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LEVEL II

REPORT NO. 8003
JULY 1980

AD A090189

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AN INTERACTIVE ACTIVATION MODEL OF THE EFFECT OF CONTEXT IN PERCEPTION PART II

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This research was supported by the Advanced Research Projects Agency and the Office of Naval Research, Personnel and Training Research Programs and was monitored by ONR under Contract N00014-79-C-0323, NR 157-437, under terms of ARPA Order No. 3767. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency, of the Office of Naval Research, or the United States Government.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 14 8003	2. GOVT ACCESSION NO.: AD-A090 189
3. RECIPIENT'S CATALOG NUMBER: 9	
4. TITLE (and Subtitle): 6 An Interactive Activation Model of the Effect of Context in Perception. Part II.	5. TYPE OF REPORT & PERIOD COVERED: Technical Report Apr[redacted]79 — Jul[redacted]80
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 James L. McClelland, David E. Rumelhart	8. CONTRACT OR GRANT NUMBER(s): 15 N00014-79-C-0323, ARPA Order-3767
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Center for Human Information Processing, University of California, San Diego, La Jolla, California 92093	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR 157-437
11. CONTROLLING OFFICE NAME AND ADDRESS: Personnel and Training Research Programs, Office of Naval Research (Code 458), Arlington, Virginia 22217	12. REPORT DATE: 11 15 Jul[redacted]80
	13. NUMBER OF PAGES: 104
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 112	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

perception
visual information processing
reading
pattern recognition
context effects
feedback
activation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper is the second part of a two-part series introducing an interactive activation model of context effects in perception. In the previous part we developed the basic form of the model and showed how it accounts for several of the fundamental phenomena of word perception. In this part, we first present a number of new experiments and show how the model accounts for these experiments. Then we propose a number of extensions of the model to such cases as spoken input, pronunciation tasks, and words embedded in sentential context.

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S/N 0102 LF 014 6601

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Finally, we discuss the strengths and weaknesses of the model, pointing out further possible extensions of the model to account for aspects of word perception currently ignored. The new experiments all revolve around what we call the "context enhancement effect." These experiments are designed to assess the roles of direct and indirect evidence concerning the identity of a letter in an input string. The direct evidence is that provided directly through the visual quality of the presentation of the letter in question. The indirect evidence is that provided indirectly by the neighboring letters. We find that the earlier and more completely information about the neighbors is presented the better the perception of the target letter. If the entire set of letters forms a word, the performance improvement is substantial. If the set of letters forms a pseudoword, there is improvement when the context letters are presented earlier. If the set of letters forms a non-word-like string, earlier presentation of the context letters provides no support for the detection of the target letter. In general, even among pronounceable strings, the more word-like the string, the more the context letters help the perception of the target letter. These results are all nicely accounted for by the present model.

An Interactive Activation Model of the Effect of Context in Perception

Part II

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Preparation of this paper was supported by NSF grant BNS-76-15024 to D. E. Rumelhart, by NSF grant BNS-76-14830 to J. L. McClelland, and by the Office of Naval Research under contract N00014-79-C-0323. We would like to thank Don Norman, James Johnston, and members of the LNR Perception research group for helpful discussions of much of the material covered in this paper.

Abstract

This paper is the second part of a two-part series introducing an interactive activation model of context effects in perception. In the previous part we developed the basic form of the model and showed how it accounts for several of the fundamental phenomena of word perception. In this part, we first present a number of new experiments and show how the model accounts for these experiments. Then we propose a number of extensions of the model to such cases as spoken input, pronunciation tasks, and words embedded in sentential context. Finally, we discuss the strengths and weaknesses of the model, pointing out further possible extensions of the model to account for aspects of word perception currently ignored. The new experiments all revolve around what we call the "context enhancement effect". These experiments are designed to assess the roles of direct and indirect evidence concerning the identity of a letter in an input string. The direct evidence is that provided directly through the visual quality of the presentation of the letter in question. The indirect evidence is that provided indirectly by the neighboring letters. We find that the earlier and more completely information about the neighbors is presented the better the perception of the target letter. If the entire set of letters form a word, the performance improvement is substantial. If the set of letters form a pseudoword, there is improvement when the context letters are presented earlier. If the set of letters form a non-word-like string, earlier

presentation of the context letters provides no support for the detection of the target letter. In general, even among pronounceable strings, the more word-like the string, the more the context letters help the perception of the target letter. These results are all nicely accounted for by the present model.

Introduction

In Part I of this paper, we developed our interactive model of word perception. We showed how the model accounted for the word letter phenomenon of Reicher (1969), the effects of the type of mask employed, the ability to read pseudowords better than other non-word strings, Johnston's (1978) finding that the amount that a word context constrains a target letter makes no difference in its detectability, and Broadbent and Gregory's (1968) results on the interaction between word frequency and bigram frequency when whole report and no mask is employed. In this part, we show how our model can be applied to a new set of experiments designed to determine the effects of one's ability to see some of the letters in a word on the ability to see the others. In the remainder of the paper, we consider various extensions of our basic model both to aspects of the visual word recognition results not yet addressed, and to phenomena beyond the simple word perception experiments involving the role of sentential contexts, pronunciation latencies for words and pseudowords, and the perception of speech. We now turn to the presentation of our new experiments and their implications for our model.

Contextual Enhancement Effects

We have argued that reading is an interactive process in which contextual clues are perhaps as important as direct evidence in the apprehension of written material. In particular, in the reading of words, each letter of the word serves as part of the context for the perception of all of the other letters of the word. Thus, as evidence is gained for one letter in a word it serves as a context for the perception of the surrounding letters. The new evidence for these letters then, in turn, strengthens them and allows them to contribute to the apprehension of still other letters. As a rule, this dynamic pattern of interactions is difficult to observe. In most experiments we only observe the results of these interactions long after they have occurred. We do not have an experimental handle on the interactions themselves. The process is acting quickly, and before we are able to make any measurements, the process is completed. In a series of experiments discussed below we have employed a technique for observing and measuring some of these detailed interactions. The basic idea of this methodology involves two manipulations:

(1) We independently manipulate the onset, offset and duration of each letter in the word. This allows us to observe effects of the quality and timing of the <u>direct evidence</u> for one letter as a function of the quality and timing of the indirect evidence for that letter as contained in the other letters.

(2) We use Reicher's forced choice technique discussed above to focus on the perception of a single letter and to control for guessing effects.

As we will illustrate below, these techniques allow manipulation of the pattern of interaction during the apprehension of a single word.

<u>Notation</u>. Figure 1 illustrates the notation to be used throughout our discussion of these experiments. A trial is represented by a box. Spatial extent is represented from left to right in the box. The content of the visual display is represented by the characters written inside the boxes. Time is represented by the vertical dimension. Therefore, duration is represented by the height of the box. Finally, an arrow over one of the positions of the box indicates the letter to be

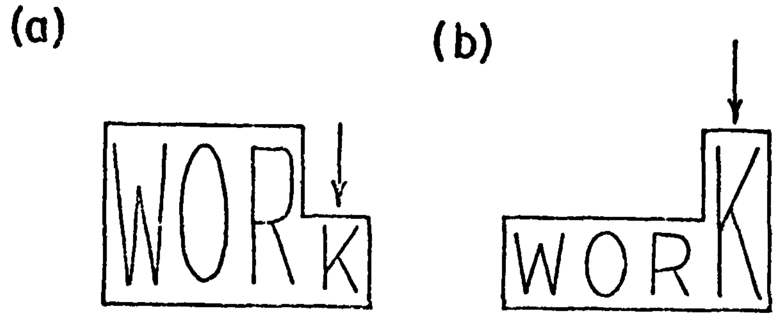

Figure 1. Notation used to represent durations of letters in different experimental conditions.

probed. Thus, Figure 1(a) illustrates a trial in which the word WORK has been presented. First the WOR appeared followed somewhat later by the K. All letters turned off simultaneously. The K was the target letter. Figure 1(b) illustrates another trial in which the work WORK has been presented, but in this case the K preceded the onset of the WOR. Again the K was probed and again all letters were turned off simultaneously.

In all experiments reported here, the offset of a letter was immediately followed by a mask. Thus, the lower end of each portion of the box represents not only the offset of the relevant character, but the onset of the mask in that letter position.

We have carried out a number of experiments employing these general techniques. In the sections which follow, we present the results of these experiments and compare these results with those generated by our simulation model.

Experiment 1

The first experiment was aimed at assessing directly the effects of variations in the quality of the contextual information on the perceptibility of a to-be-probed target letter. This was accomplished by presenting the context letters either longer or shorter than the to-be-probed target letter. The critical letter duration was fixed so that the quality of direct information for the probed letter was constant over the five conditions. Only the quality of the context letters varied. In all cases the offsets were synchronous; only the onsets varied.

Method

Procedure. The basic procedure for Experiment 1 is illustrated in Figure 2. The trial began with a fixation field. When the subject was ready, he pressed a button and 250 milliseconds later a four letter word was presented. The word could be presented in one of five configurations. In each case all letters were turn off simultaneously. In each case, the total duration of the "critical", to-be-probed letter was the same. However, in the different conditions the context letters could either precede or follow the onset of the critical letter. Since the duration of the critical letter was adjusted between and within subjects to assure near 75 percent performance, the exact duration of the context letters had to be adjusted as well. The five conditions were characterized by the ratio of the duration of the context over the duration of the critical letter. Ratios of 3:5 (.6), 3:4 (.75), 1:1 (1.0), 4:3 (1.33), and 5:3 (1.67) were employed. Note that a ratio of 1:1 represents a normal presentation in which the context and critical letters came on and went off simultaneously. The 4:3 and 5:3 ratios involved cases in which the context preceded the critical letter and the 3:5 and 3:4 ratios were cases in which the critical letter preceded the context. Trials of each ratio condition were mixed together in random order, and in no case was the subject prewarned about which ratio condition was coming up or which letter was the critical letter. The presentation of each word was immediately followed by a presentation of the mask illustrated in the Figure. As illustrated, the mask consisted of

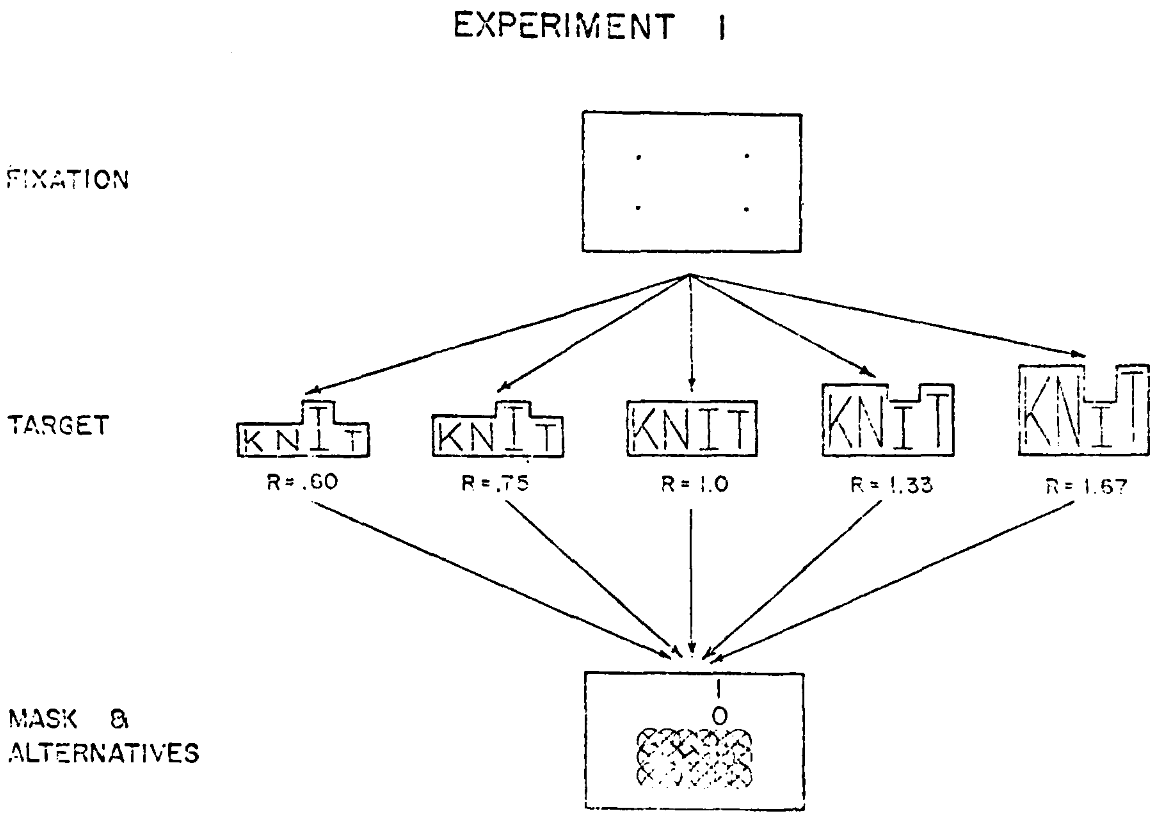

Figure 2. Display conditions used in Experiment 1.

an overlapping set of X's and O's.

Finally, 100 milliseconds after the onset of the mask, a pair of letters appeared immediately above the critical letter. The subject's task was to indicate with a button press which of the two letters had actually been presented in that position. As in Reicher's original paradigm, the letters were chosen so that either would form a word when combined with the context letters. Thus, in the Figure the I and O could have been combined with the KN T to form either the word KNIT or the word KNOT. Moreover, half of the subjects were actually presented with one of the words and the other half with the other word.

It is useful to realize that for the durations involved in these experiments subjects were not aware which condition they were seeing. The total presentation time was short enough to look like one singular presentation of a single word.

The entire experiment was controlled by a PDP9 computer. Stimuli were displayed on a CRT screen located about 40 cm in front of the subject. At this distance, a whole display word subtended a visual angle of about 30 degrees. As mentioned before, the duration of the target letter was adjusted for each subject after every block of 25 trials to insure an average of about 75 percent correct responses. An initial duration of 50 milliseconds for the critical letter was employed. Thereafter the new duration was determined by the following equation:

$$d_{new} = d_{old}(1+.75(.75-\frac{N}{25})) \quad (1)$$

where N is the number of correct responses in the block. The trials were ordered in such a way as to insure that each of the five conditions occurred five times per block.

Stimuli. The experiment was designed to study the perception of as many of the four letter words in English as possible. Thus, all four letter words listed in the Kucera and Francis (1967) corpus with frequency of at least five were obtained. Then, the words were arranged into pairs differing by a single letter, with the frequencies of the two members of each pair matched as closely as possible. Those pairs in which the Kucera and Francis count differed by more than a factor of two were eliminated. This left a total of 750 pairs. Each subject was shown one member of each pair for a total of 750 trials per subject. Since all available pairs were used, we did not keep the number of tests in each serial position constant. There were 303 pairs testing the first serial position, 118 pairs testing the second, 153 pairs testing the third, and 176 testing the fourth. The entire list of pairs is presented in Appendix 1.

Subjects. The ten subjects run in this experiment were undergraduates at the University of California, San Diego. They were either given course credit or paid for their services.

Empirical Results

The aim of the experiment was to assess the effects of the duration of the context on the perception of the critical letter. Under these conditions *subjects were unaware of the fact that onsets varied*.

Phenomenologically some words were easier to see than others, but the time differentials were small so that within the mixed block design the differences were not apparent. Nevertheless, performance on the two alternative forced-choice was strongly affected by the quality of the context.

The basic results are shown in Figure 3. For the lowest ratios subjects responded correctly less than 65 percent of the time. For the highest they responded correctly over 80 percent of the time. These points are based on a total of 1500 observations in each condition, so that the 95% confidence interval around each point is about plus or minus 2.5 percent.

To appreciate the magnitude of this effect it should be kept clearly in mind that since the Reicher paradigm was employed, the context was <u>completely irrelevant</u> to the decision between the two letters —both made words of roughly the same frequency in the language and subjects had no awareness of the manipulation. The entire effect of the variations in context must be attributed to ways in which variations in quality of the contextual letters directly effected the processing of the critical letter during the perceptual process.

<u>Theoretical Results</u>

Now, it should be clear that the model we have been developing will account for these data. Consider first the case in which the context presentation begins before the onset of the critical letter. When the context is turned on it begins to activate the relevant letters. These

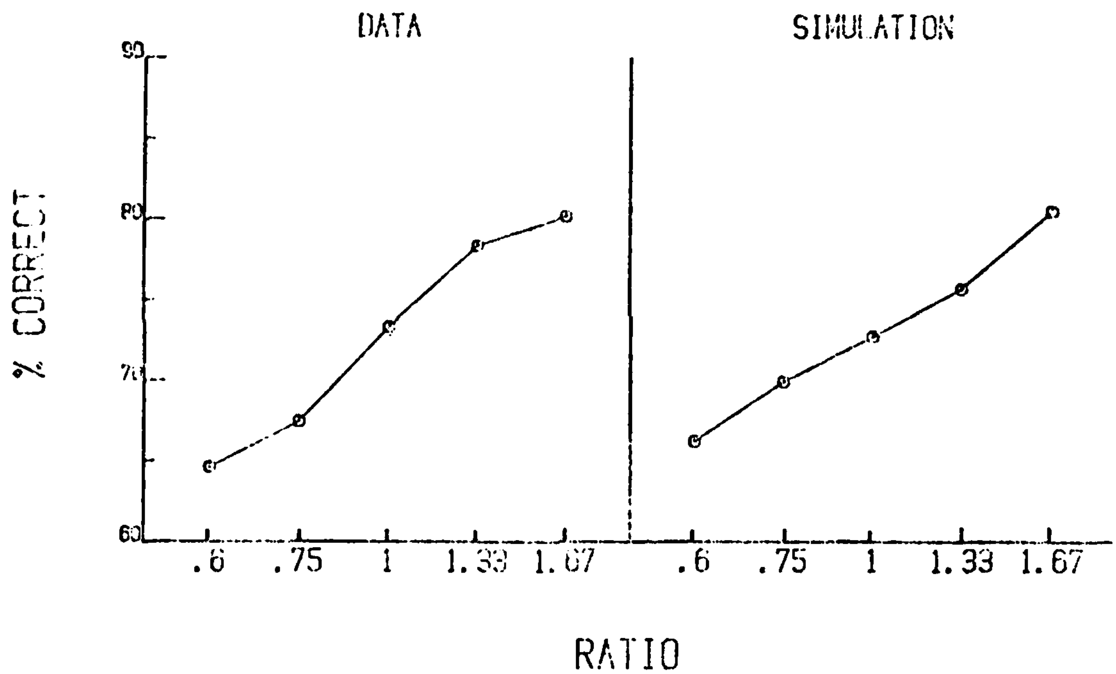

Figure 3. Percent of correct forced-choice response to the critical letter, as a function of the relative duration of the context to the duration of the critical letter. The panel on the left shows the actual data from the experiment, the one on the right shows the results of the simulation run described in the text.

letters, in turn, activate those words consistent with the context, including the yet-to-be-presented critical letter and the alternative. These partially active words, in turn, strengthen the contextual letters and awaken the "missing" letters. Then, when the critical letter is turned on, the letter strength can quickly grow and reach a relatively high value. Figure 4 indicates the activation resulting from presentation of the word SHIP for the words 'ship' and 'whip', for the letters 's', and 'w', and for the output probabilities for 's' and 'w' for ratios of 1:1 and of 2:1. Clearly, presenting the context for twice as much time as the critical letter has the effect of increasing forced-choice accuracy, just as we observed in the data.

In order to see if the magnitude of the effect produced by the model is about the same as that observed in the data, we ran a simulation of the experiment. In this and the other simulations of the context enhancement experiments a sample of ten pairs differing in each serial position was chosen. One element of each pair was chosen to be presented to the model. Thus, a total sample of forty items were included in the simulation. Figure 3 shows the results. Rather obviously, the model does account for the approximate magnitudes observed. For a ratio of .6 our simulation yielded about 66 percent correct. For a ratio of 1.67 the simulation generated a value of 81 percent correct. This is exactly the same range of values observed in our experiment. The basic parameters used here were those employed in the simulations reported in Part I. The moderate display quality input parameters were used, and the letter-word inhibition was set at .04. As we found in the simulations reported in Part I, the value of this parameter makes little

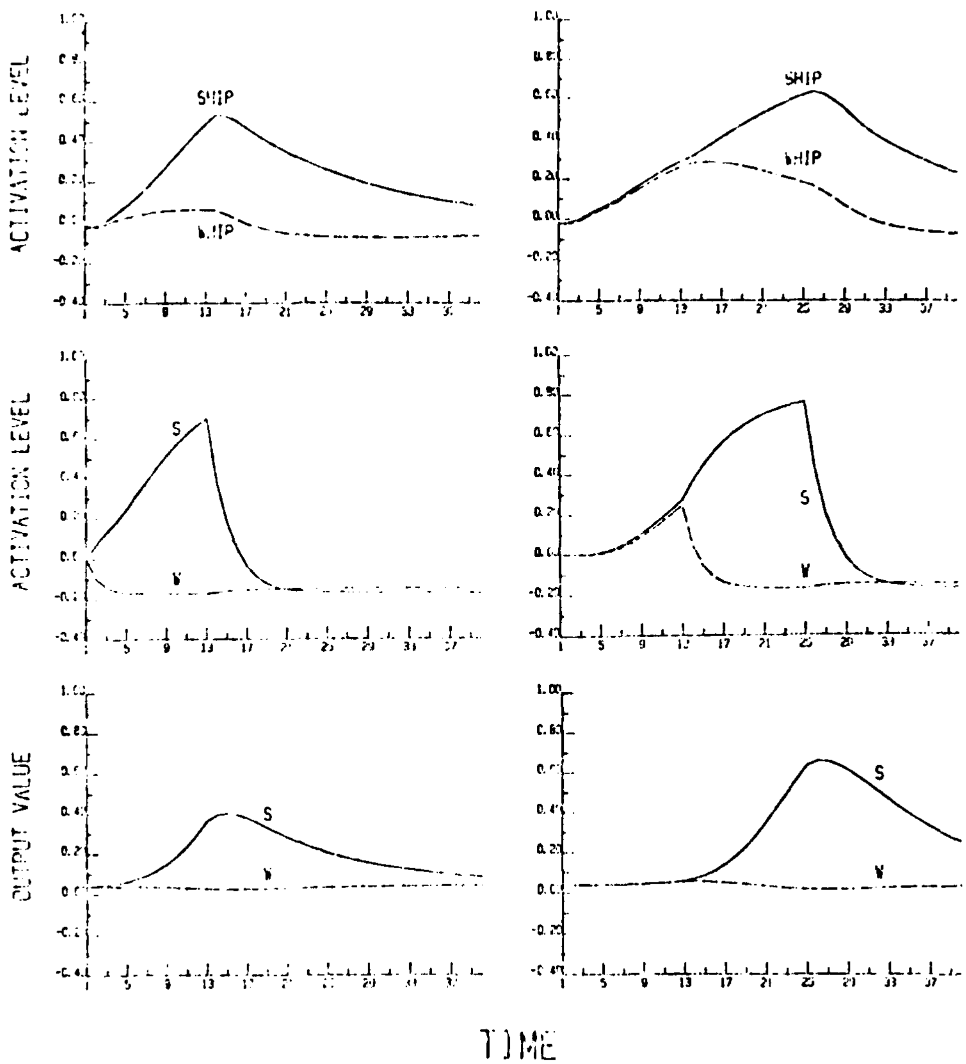

Figure 4. Activations and the word and letter levels, and output values, resulting from the presentation of the word SHIP, in the case where the S and the HIP are presented in a 1:1 and a 2:1 ratio.

difference when actual words are shown: indistinguishable results are obtained using the larger value of .21. The duration used was 13 time cycles of our program. This lead to an optimal readout time of 16 time cycles after the onset of the critical letter.

Experiment 2

It may be argued that the effects observed in these experiments are merely some artifact of the peculiar timing sequences used. Perhaps, for example, the results are due to some sort of warning signal effect rather than to the information which one letter can dynamically contribute to the processing of its neighbor letters. To test this hypothesis, the effects of the ratio manipulation were assessed on letters embedded in numerals, and on letters embedded in words. The ratio of context duration to critical letter duration was either 1:1 or 2:1. On half of the trials subjects saw words just as before, on the other half of the trials the the normal letter contexts were replaced by numerals randomly chosen prior to presentation. Since the numerals could not contribute information to the perception of the critical letter, longer durations for the number context should not aid the perception of the critical letter.

Procedure. The general procedure was nearly identical to the procedure used in Experiment 1. Again, ten subjects were run. The 750 different trial types were divided as equally as possible among the four conditions (two context duration ratios by word vs numeral context); there were 188 trials in each of the word conditions and 187 in each of the numeral conditions. As before, the critical letter was presented for the same duration in each condition.

Results. The basic results for this experiment are given in Figure 5. As expected, the usual advantage for the critical letter when given extra contextual information was obtained. However, no such advantage was found with the number context. It would thus appear that the effect of context quality is truly an effect in which the context letters actually contribute to the apprehension of the critical letter. There is no indication that the result is merely a warning signal effect or some other artifact of this sort.

It is useful to determine whether the magnitude of the overall difference between the number contexts and the word contexts is approximately the size expected by our model. To determine this, we adjusted the overall percent correct to approximately coincide with the words and looked at the results for the case of a completely irrelevant context. The results of this simulation are also shown in the Figure. Rather obviously, the model does account for the basic effects. These results were obtained with a duration of 15 cycles and a readout time of 17 cycles after the onset of the critical letter. The results are approximately of the right magnitude. The major problem is that the items with number contexts are about 4 or 5 percent worse than the simulated results. It is possible that the number contexts were in fact occasionally confusing or misleading the subjects, leading to even lower response probabilities than in the case of no context. Another discrepancy is the fact that the model overpredicts the size of the enhancement effect for words. Generally, though, the experiment and the

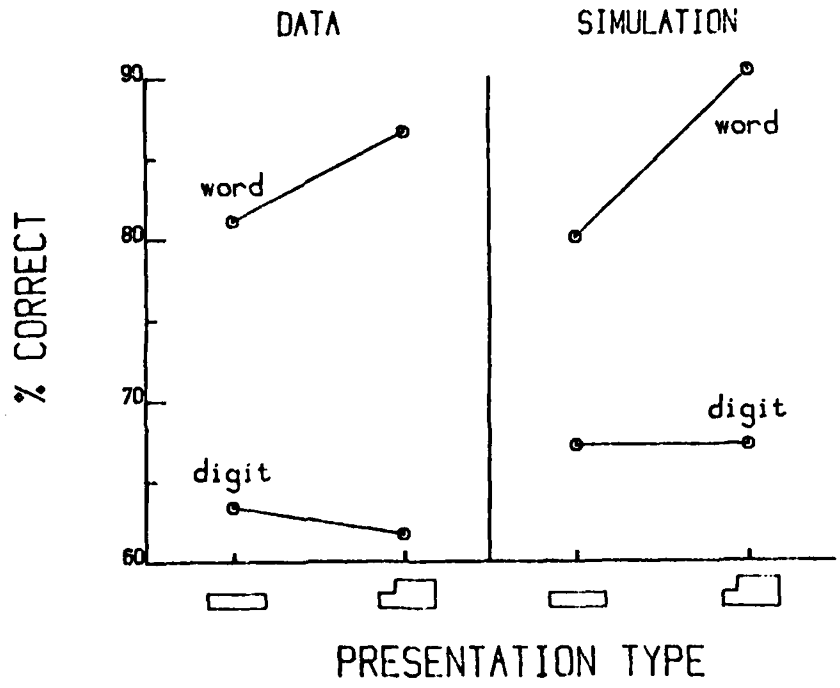

Figure 5. Effects of doubling the duration of the context on the perception of letters in words and in strings of numerals, from Experiment 2. Actual data is shown on the left, and the result of the simulation is shown on the right.

simulation model produce the same pattern of results.

Experiment 3

If, as suggested by our model, the contextual information is having its effect very early in the perceptual process, the exact timing of the extra contextual information should be very important. In our model, it is the fact that the contextual information comes on early and primes the nodes for a word or words containing the critical letter which is important. If the critical information followed the presentation of the critical letter it should not help very much. In order to test this implication, another experiment was carried out. The basic design of this experiment is illustrated in Figure 6. The design is simple. All letters were presented for the same duration, only the order of presentation varied. Three conditions were used in this experiment:

(1) The contextual information was first presented and on its offset the critical information was presented.

(2) Both context and critical letter were presented simultaneously and thus were turned on and off concurrently.

(3) The critical letter was presented and then, immediately on its offset the context was presented.

The duration of the context and the critical letter was the same in all cases.

Procedure. Again the procedure adhered to the conventions established in Experiment 1. Each subject was presented with 240 context late trials, 270 simultaneous trials and 240 context early trials. Ten subjects were run in all.

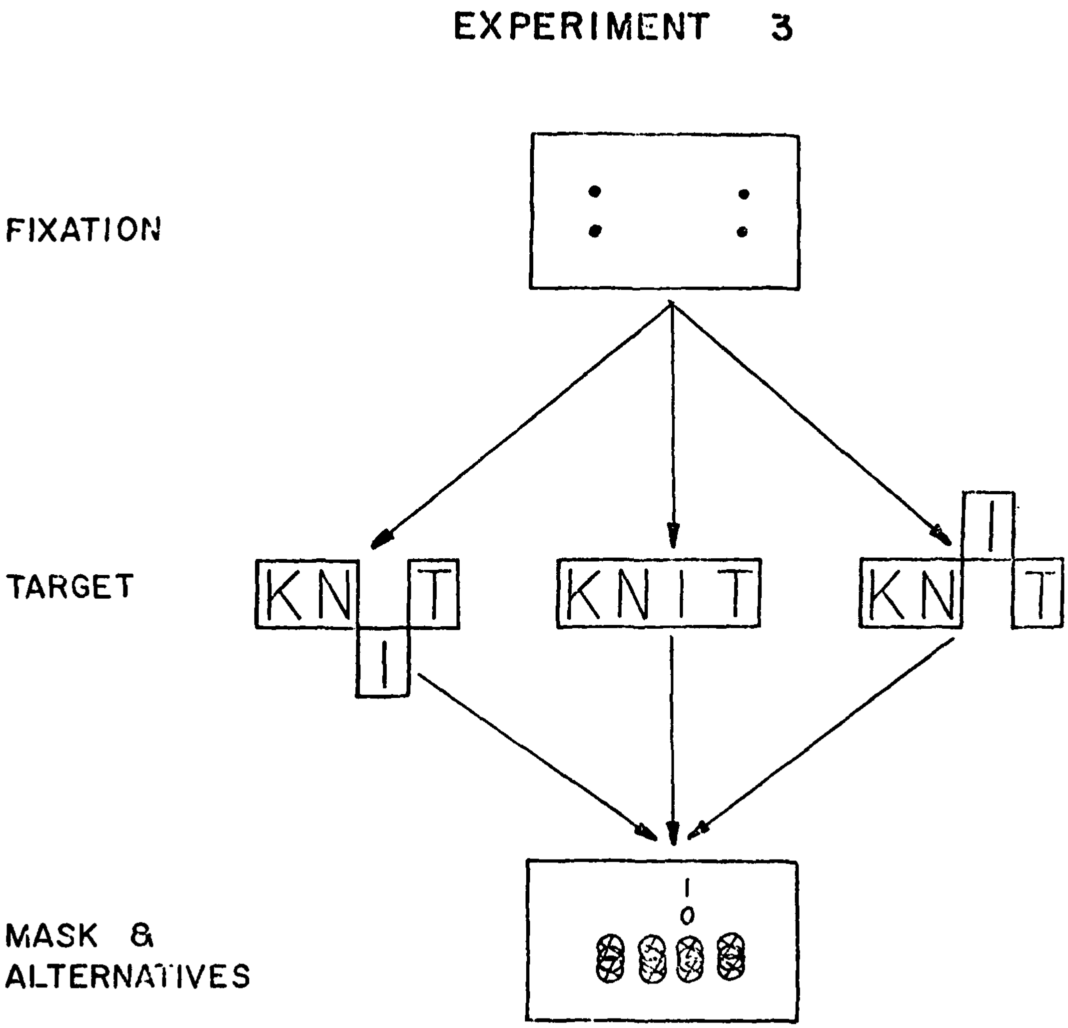

Figure 6. Illustration of the design of Experiment 3 investigating the effects of presenting the context before, after, or simultaneous with the target.

Letters were masked individually, so that the offset of each letter could be followed immediately by a mask for that letter. To accomplish this, the mask was changed from Experiment 1 to the one illustrated in the Figure. Except for this change, the physical conditions of the experiment were exactly the same as those of Experiment 1.

Results. The basic results of this experiment are given in Table 1. As expected, there is a substantial disadvantage for the context to come late. However, the early context does not seem to produce superior overall perception compared to the simultaneous context.

Table 1 also shows the results of our simulation run for this experiment. (The duration used was 14 cycles and the readout was at 16 cycles after the onset of the critical letter.) The simulation agrees well with the data on the relative inferiority of the letter then context condition. However, the simulation produces a 6 percent advantage for the context early condition compared to the simultaneous condition. These two conditions came out about the same in the data.

A clue to the reason for the discrepancy is given in Figure 7 which shows the serial position curves for each of the conditions. This Figure shows that whereas the serial position curve for the simultaneous condition is relatively flat, the serial position curves for the context early and context late conditions are curvilinear. The context late condition shows the traditional bow-shaped curve typical of random letter strings and the context early curve actually bows in the opposite direction. The simulations, on the other hand, show essentially flat serial position curves for all three conditions. Obviously, we have not

Table 1

Experiment 3

Proportion Correct Responses as a function of the relative times of offset for the target and context letters.

	Presentation Condition		
	Context Late	Simultaneous	Context Early
Observed	.682	.742	.749
Simulation	.651	.765	.827

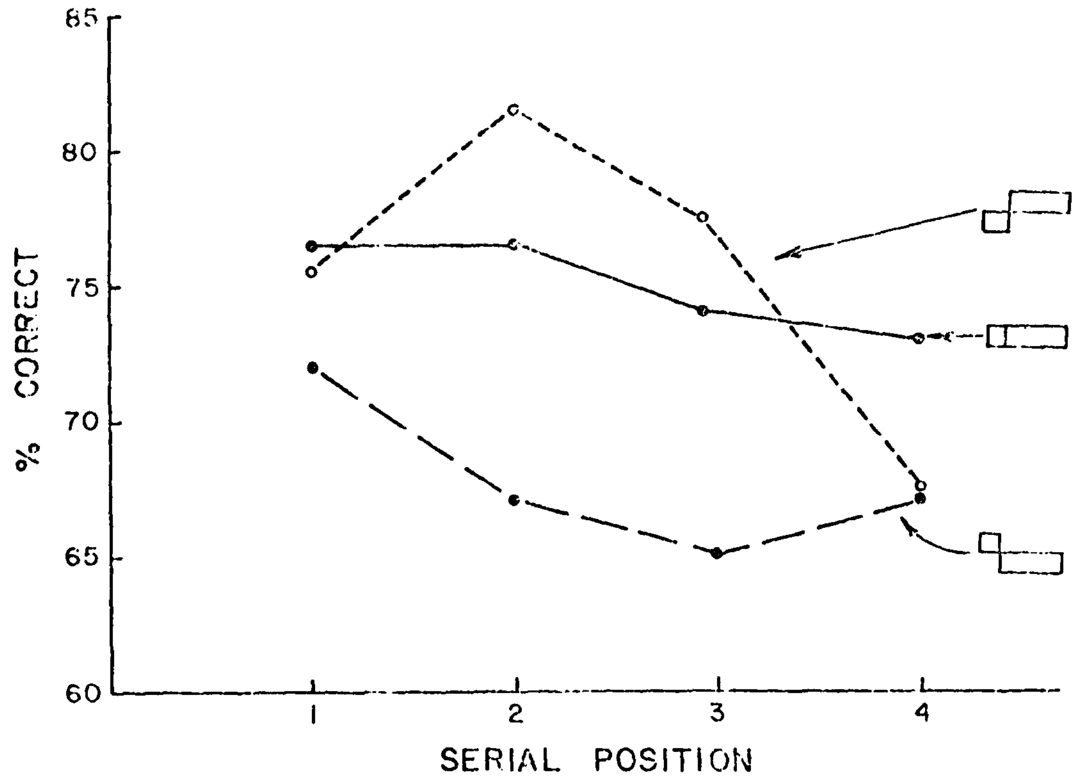

Figure 7. Serial position curves for the context early, simultaneous, and context late conditions of Experiment 3.

built into our model the factors which cause the serial position curves to have the shape that they do. In a later section we discuss some possible mechanisms. For the moment, however, simply consider what the effects of a sort of "outside-in" processing mechanism might be. If scanning somehow proceeded from outside in, the outside letters would generally have an advantage if they were presented early in the interval and would have a disadvantage if they were presented late. This is exactly what we find. In the context first condition, the critical letters are presented late in the interval (after the context has been presented) and first and fourth serial positions are depressed relative to the middle positions. On the other hand, in the context late condition before the context in presented the end letters have an advantage over those in the middle of the word.

When we look at the letters in the middle of the word we see a pattern much more similar to that observed in our simulations. These two serial positions produce the values given in Table 2. Clearly, the results generated by our model offer a rather close match to the central serial positions. The difference between the overall simulations results and the overall results of the experiment appears to be entirely due to effects on the first and last serial positions.

In this experiment then, it would appear that we have been able to affect the times at which the critical information was available and thereby either <u>facilitate</u> the effect of the contextual information on the perceptibility of the critical letter, or nearly <u>eliminate</u> the effect of the contextual information. The pattern of these effects

Table 2

Experiment III

Proportion Correct for Serial Positions Two and Three as a Function of Presentation Condition

	Presentation Condition					
	Serial Position 2			Serial Position 3		
	Context Late	Normal	Context Early	Context Late	Normal	Context Early
Observed	.671	.764	.813	.650	.741	.770
Simulated	.649	.774	.845	.653	.765	.791

would seem to confirm to a substantial degree the assumptions of the model involving the priming effect of the context letters on the perceptibility of the critical letters.

Experiment 4

Suppose that we leave the context information on for a fixed interval and simply vary the place in the interval when the critical information is available. Reasoning from the model, if the critical information is presented early in the interval we would expect that the extra contextual information would have less time to prime the relevant word nodes than if the critical information were presented later in the interval. Experiment 4 tests this prediction. It also reintroduces the digit context control to eliminate the possible masking or warning signal effects of the asynchronous presentation of target and context per se.

Method. The design of this experiment is illustrated in Figure 8. The design is a 2x2 factorial design. The critical letter was presented for the same duration in all conditions and the context was always presented twice as long as the critical letter. One factor was the timing of the critical letter. It could occur either early or late in the interval. Either the context and the critical letter were turned on simultaneously and then the critical letter was turned off half way through the presentation interval or, conversely, the context was turned on first and when the total presentation interval was half over the critical letter was presented. In this case, all letters were turned off simultaneously. Half of the time it occurred early and half the

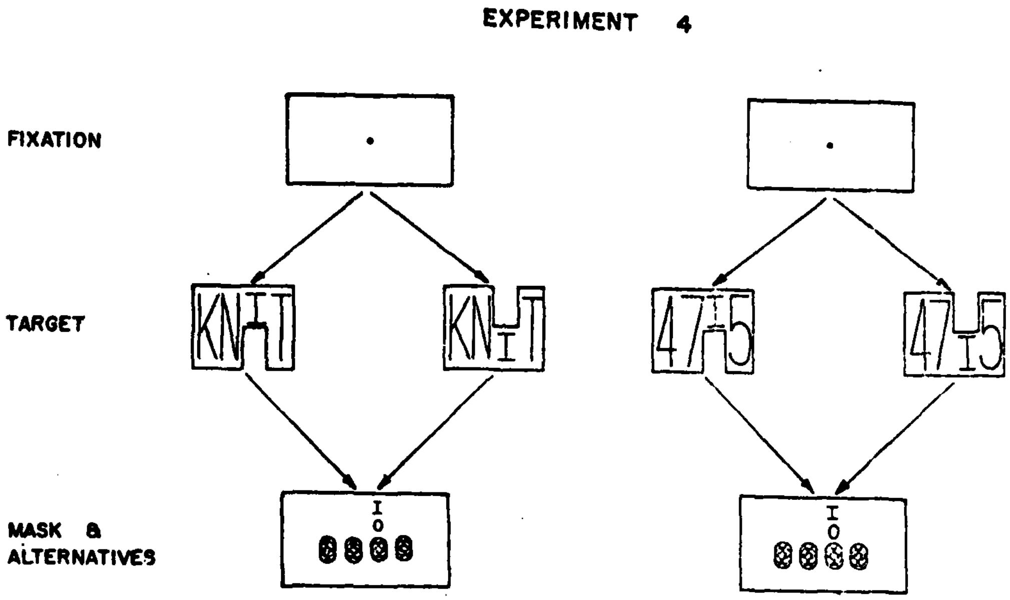

Figure 8. Illustration of the design of Experiment 4, in which the critical letter is presented either early or late in the presentation period containing the context. As in Experiment 2, the context either forms a word with the critical letter, or it is a random sequence of digits.

time it occurred late. The second factor involved the nature of the context. Half of the time the context was normal and the entire string made a word and half of the time the contextual letters were replaced by random numbers. Of course, from Experiment 2, we always expect the word context to be better than the number context. More importantly, if the advantage of the critical letter being late in the interval does not depend on the nature of the context, we expect that the same difference between early and late will occur for the number context as the word context. On the other hand, if, as our model suggest, it is the early availability of the contextual information which is important, we expect no difference in the case of the number context. The duration of the critical letter was the same in all conditions.

Experiment 4 was carried out somewhat differently from the previously discussed experiments. Rather than use the entire set of 750 stimulus pairs, which involved an unequal number of tests for the various serial positions as described above, we chose a new set of 384 pairs of items with 96 pairs for each serial position. Since there was evidence from the previous experiments that performance was somewhat worse for words beginning with a vowel (whether or not the first serial position was tested), all of the items for this experiment began with consonants. The entire list of 384 pairs is given in Appendix 2.

The general procedure for this experiment was nearly the same as the previously described experiments with a few minor exceptions. The fixation point was modified from that illustrated in Figure 2 to the one illustrated in Figure 8. Trials were entirely self paced. After the onset of the fixation point subjects advanced to the presentation of the stimulus by pressing a button. The trial appeared 250 milliseconds after the button was pressed. The experiment was controlled by a PDP11 computer rather than the PDP9 computer used in the previous experiments. Subjects were only given 384 trials, one of each half of each pair. Of course, across subjects each element of each pair occurred equally often. In this experiment, 32 subjects chosen as before were run.

Results. The basic results of this experiment are given in Figure 9. As expected, the critical letters are much better perceived in word contexts than in numeral contexts. There is no advantage, in the case of a number context, for the critical letter to come late in the interval. There is in fact a very slight difference in the opposite direction. However there is a significant 4 percent advantage favoring the critical letters occurring late in the interval, $F(1, 31) = 5.21$, $p < .05$. Of course, the interaction between Context Type and Presentation Ratio is also significant, $F(1, 31) = 6.53$, $p < .05$. It thus does not appear that the temporal pattern of events alone accounts for this advantage. Rather it appears that, as our model suggests, there is a real priming of the critical letter by the early presentation of the context.

The Figure also shows our simulation results for this experiment. The simulation results show the same general pattern of results as those we have observed. However, there seem to be a couple of problems. First, as before, the number contexts are slightly worse than our simulations would suggest. Secondly, the differences between early and late

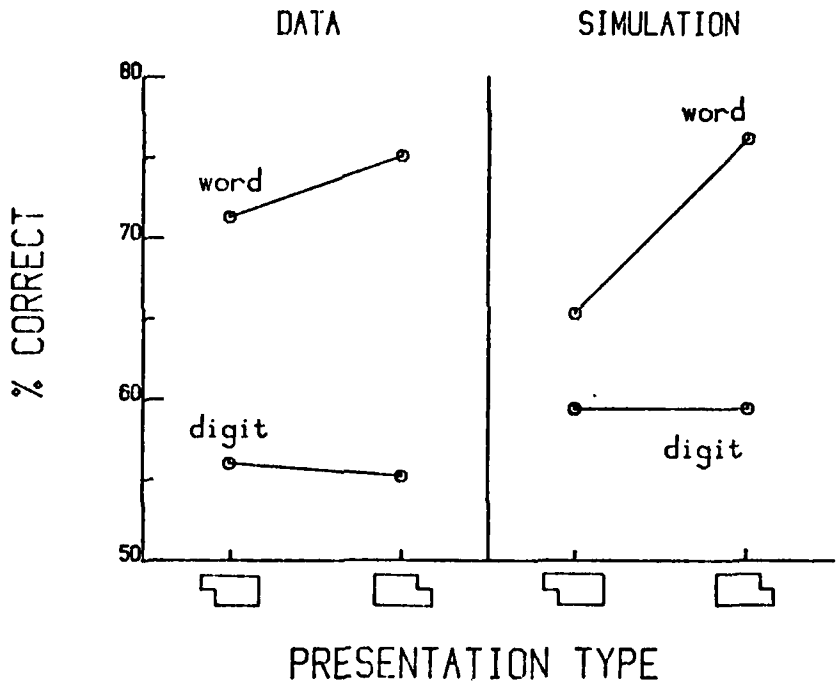

Figure 9. Percent correct responses for strings containing word and digit contexts as a function of whether the target letter came early or late in the interval from Experiment 4.

presentations are somewhat larger than actually found in the data. There are several possible reasons for this, but generally, it seems that the model overestimates the speed with which the mask effects the critical letter. That is, when the mask is turned on in our simulations, it immediately begins to reduce the activation level of the critical letter thus rendering totally ineffective the remaining contextual input. In fact, subjects do appear to make some use of context following the masking of the critical letter. In spite of these problems, the results of the experiment and of the simulations do appear to be basically consistent with the expectation that contextual information *does* in some sense *prime* those letters consistent with the context and thereby aid in the perception of those letters.

Experiment 5

According to the model we have been developing, contextual information can substitute for a lack of direct sensory information and, conversely, direct sensory information can substitute for contextual information when that is in short supply. In Experiment 5 we compared the relative contribution of additional direct evidence as compared to additional contextual information. The basic design of this experiment is illustrated in Figure 10. Here we have basically a 2x2 factorial design in which one factor is the duration of the context and the other factor is the duration of the critical letter. The critical letter was either presented for duration D or duration 2D and the context was either presented for D or 2D milliseconds independent of the duration of the critical letter. D was varied for individual subjects to insure a 75

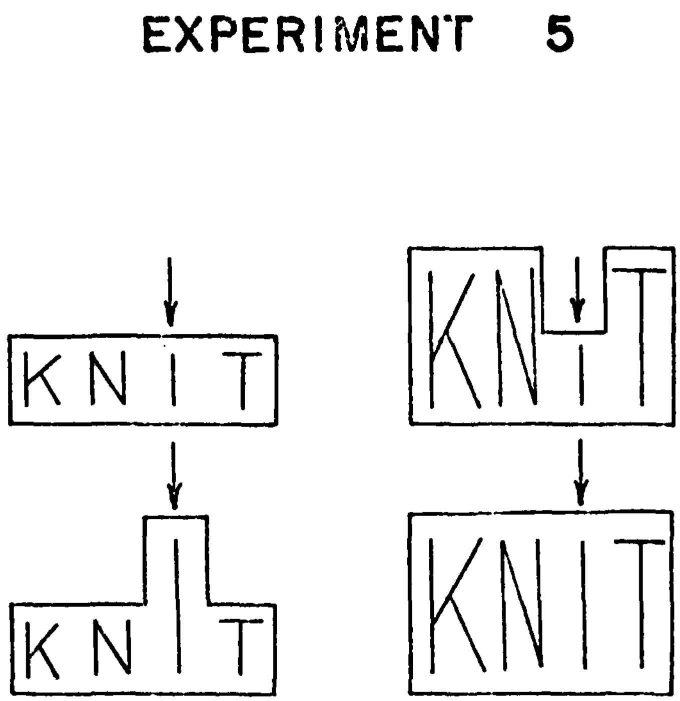

Figure 10. Illustration of the design of Experiment 5, comparing the effects of direct information (duration of the target letter) and indirect information (duration of the context letters).

percent correct response rate for each subject. This experiment was run with the stimulus set and physical conditions of experiments 1-4. Again, ten subjects were run.

The basic results are illustrated in Figure 11. Clearly, there is a tradeoff. Either added direct information in the form of longer durations of the critical letter, or added indirect information in the form of longer durations for the contextual letters increase performance substantially. In this case, the direct information is somewhat stronger than the indirect. It is interesting to note that although both main effects are highly significant, the interaction between the two sources is non-significant. The two information sources thus appear to add. The Figure also shows the results of our simulation. Clearly, there is a tradeoff. The simulation also shows an essentially additive effect of the two factors. However, whereas the simulation shows an enhancement effect of about the appropriate magnitude, the effect of direct information is somewhat stronger in the simulation than in the observed data.

Experiment 6

We have been arguing throughout this section that the perceptibility of the critical letter depends on the perceptibility of the letters in the context. Does this dependency vary over different context letters? It is possible to get some evidence on this by increasing the quality of arbitrary subsets of the context letters to see whether the degree to which this subset of contextual letters predicted the critical letter was correlated with the detectability of the critical letter in that situation.

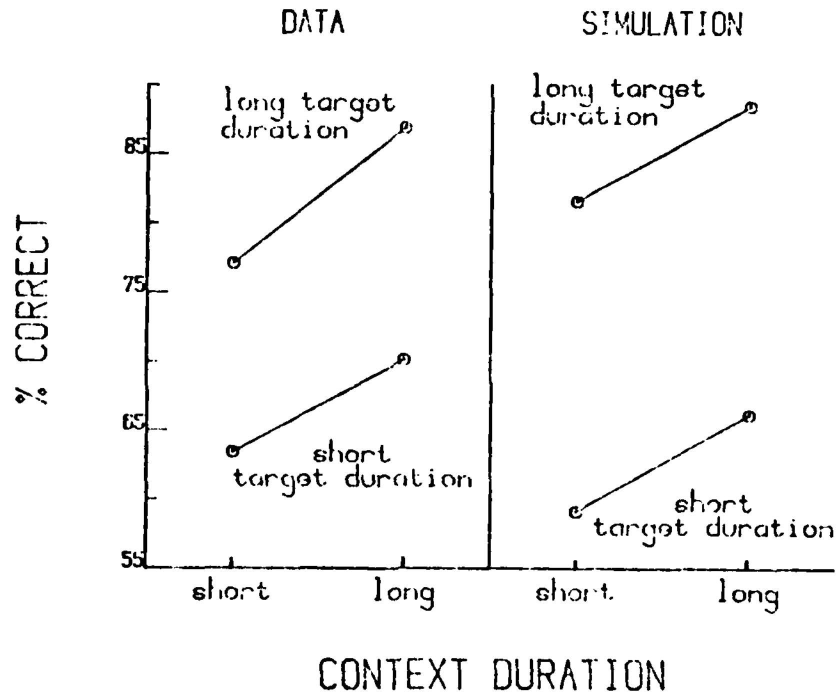

Figure 11. Percent correct responses as a function of the duration of the context and target presentations, from Experiment 5. Again, the left panel shows the actual data, and the right shows the results of the simulations.

The basic conditions of Experiment 6 are illustrated in Figure 12. There are a total of 32 conditions. Each of the four serial positions were tested under eight context conditions. In each of the eight conditions, a different (possibly null) subset of the context letters was presented longer than the target letter. The longer durations were always twice the shorter ones.

The stimulus set and the physical conditions were those of experiments 1-4. A total of 24 subjects were run--each for 750 trials.

The results from this experiment are also presented in Figure 12. There are three results which are apparent from this experiment. First, clearly, the more contextual letters which are enhanced, the better is the performance. Figure 13 shows the average percent correct responses over all conditions as a function of the number of letters of context to receive the longer duration. This, of course, accords with expectation. The more context letters to be primed, the better the ultimate performance on the critical letter. The second result is a little more subtle. The closer the context letter to the critical letter the stronger its effect on the perceptibility of the critical letter. We have tried to determine the effect of the increased duration of one letter, l_i on the detectability of letter l_j by taking the difference between the average percent correct on letter l_j as a function of whether or not letter l_i was enhanced. The results of this computation are shown in Table 3. The entries show the effect of the information provided for one letter on the detectability of another. The biggest entries in the Table are generally for adjacent letters. Thus, for example, on aver-

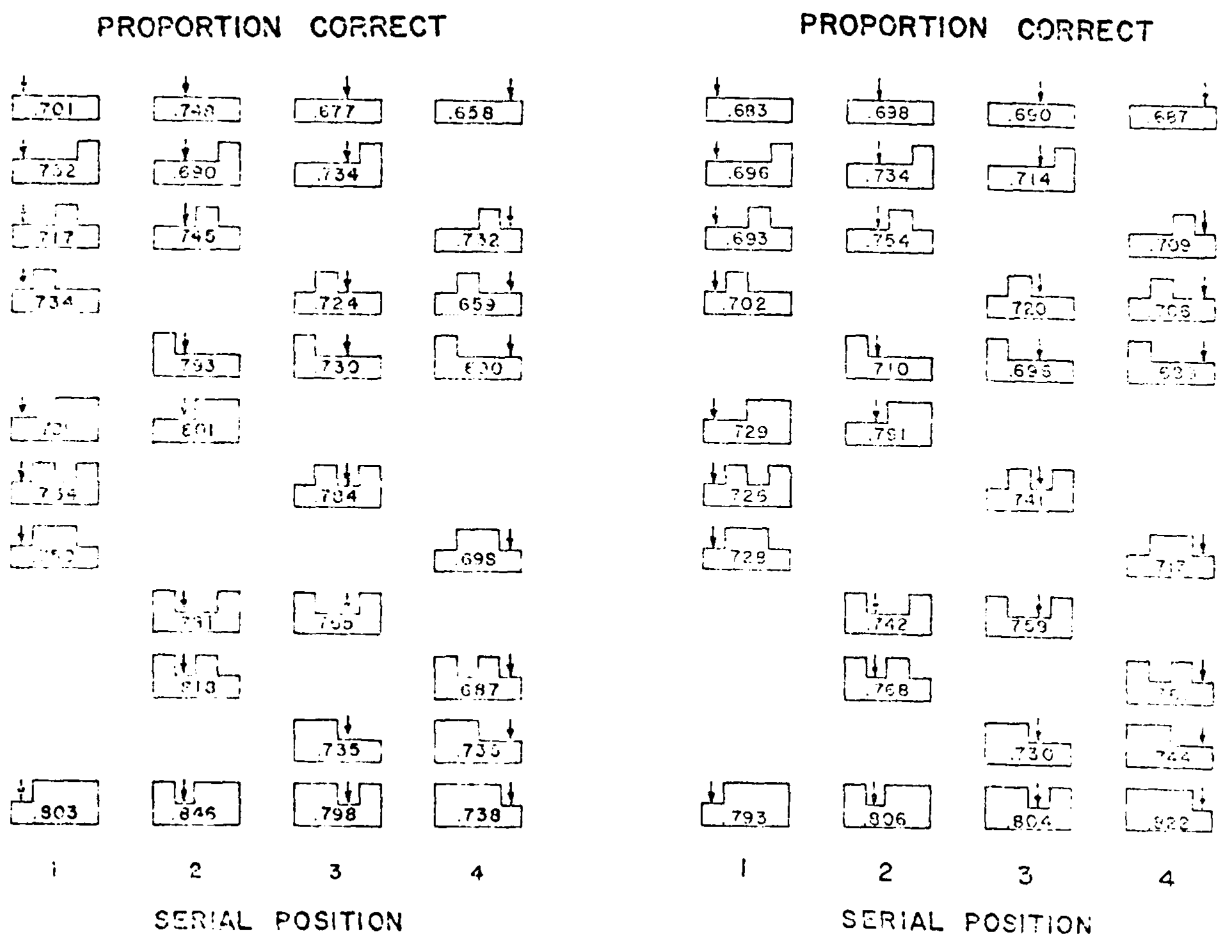

Figure 12. Illustration of the 32 different conditions used in Experiment 6 and percent correct (forced-choice) for each condition. Actual data are on the left; the results of the simulation are on the right.

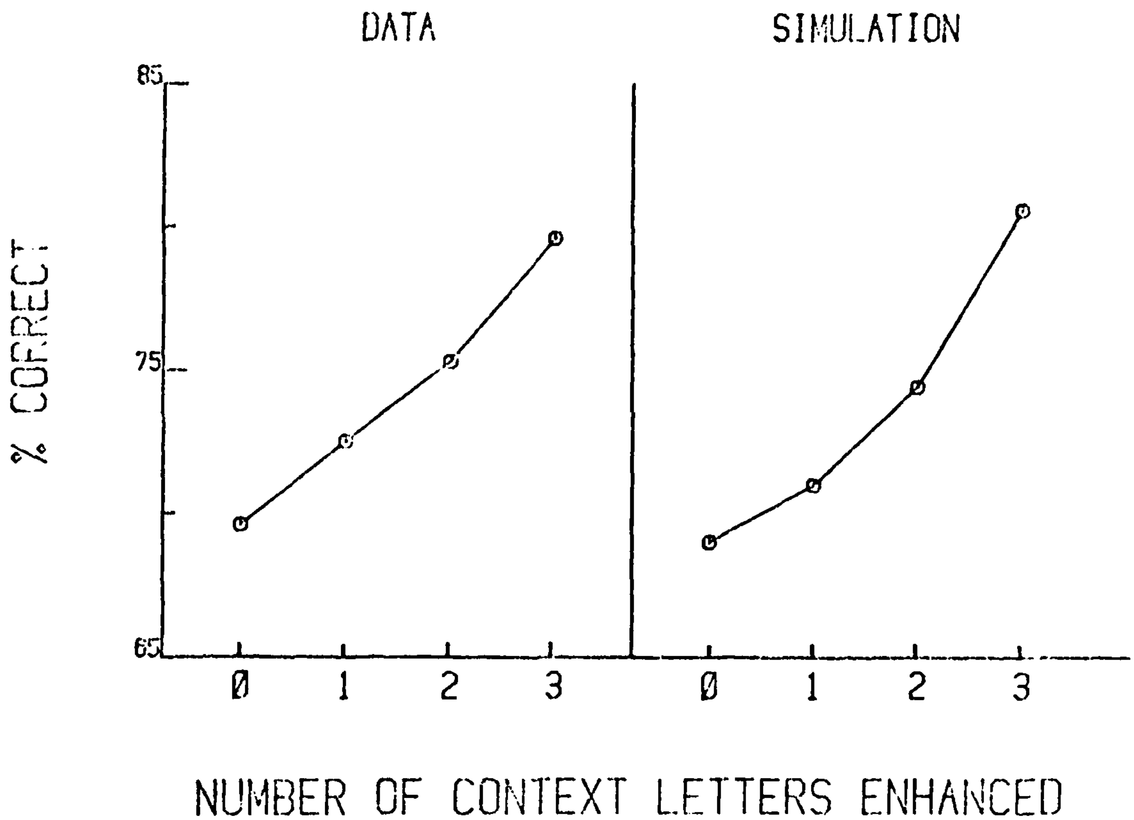

Figure 13. Average percent correct responses over all conditions as a function of the number of letters of context to receive the longer duration presentation.

Table 3

Serial Position of Enhanced Context Letter

Target Position	1	2	3	4
1	—	3.9	1.1	3.3
2	6.4	—	4.0	0.4
3	2.7	3.3	—	5.3
4	2.6	1.6	2.9	—

age, the presentation of the first letter as a context letter facilitates performance on the second letter by 6.4 percent. Similarly, early presentation of the fourth letter facilitates performance on the third letter by 5.3 percent. The presentation of the third letter increases performance on the second letter by about 4 percent etc. More distant letters appear to generally have a lesser effect. A third result, also visible in the Table, is that initial and final letters have stronger effects than internal letters.

The complete results of our simulation run for this experiment are shown in Figure 12. Since the performance levels for the simulation show about the same performance levels for all four serial positions and the observed data do not, it is easier to compare simulation data and observed data independent of actual level of performance (serial position effects have thus far been ignored in our model; we discuss possible sources of these effects in a later section.) Figure 13, for example, shows the average percent correct responses obtained in the simulation data as a function of the number of letters of context receiving extra information. Obviously both model and data show the same dependency of response probability on number of context letters presented early.

Table 4 shows the relative effects of each specific context letter on each other letter. A comparison with Table 3 will show some gross similarities, although the two differ somewhat. Adjacent context letters show a greater benefit for target letters in serial positions 3 and 4, but not for targets in positions 1 and 2. Furthermore, the gen-

Table 4

Target Position	Serial Position of Enhanced Context Letter 1	2	3	4
1	—	1.3	3.1	4.3
2	3.7	—	3.4	4.2
3	3.4	5.9	—	5.2
4	3.5	3.6	4.6	—

erally stronger effect of end letters is not as evident here as it is in the data. This latter discrepancy is presumably related to the absence of basic performance differences as a function of serial position in the model.

It is interesting to consider why the model shows any effects of the relative position of the critical letter and enhanced context letters. At first glance we would expect no such effects, since the feedback is based on activation of nodes at the word level, and all four letter positions feed activation to these nodes on an equal basis. However, it turns out that, on the average, the closer two letters are in a word the more knowledge of one tells us about the other. That is, the closer two letters are in a word, the more likely they are to occur together in many words in the language. Thus, the "adjacency effect" exhibited by our model derives from the fact that nearby letters are more likely to activate words containing the critical letter than are more distant letters. The failure of the adjacency effect to show up in all serial positions seems to be due to characteristics of the particular sample of items used in the simulation. Clearly, according to the model, the exact nature of the help that a context letter offers a word depends on what that word is. The simulations were done over a subset of ten words for each serial position. It turns out that all of the first position items in the simulation began with a single consonant followed by a vowel. In such items, the likelihood of co-occurrence of the first and second letters tends not to be high, since each consonant can occur with each vowel in words in English, with very few restrictions.

Experiment 7

We have, in the experiments reported thus far, investigated the context enhancement effect on the presentation of words. We have already seen that the fact that a string forms a word is not an essential characteristic for the word letter phenomenon. Does the early presentation of a context facilitate the perception of letters in nonwords as well as word strings? The remaining experiments constitute an investigation of the existence and nature of the context enhancement effect as a function of the 'wordness' of the input string. These data also allow us to investigate the plausibility of the account offered by our model for pseudoword perception in general. The first experiment of this series is concerned simply with the assessment of whether the context enhancement effect occurs with nonwords and with the comparison of the magnitude of its effect as compared with the effect for words.

Method. The experimental procedure and the set of word stimuli used were those described in Experiment 4. One pair of pseudowords was formed for each pair of words by the following general procedure: For each pair of words, such as WORD and WARD, the letter most distant from the critical letter was changed to yield a pronounceable nonword. In this case, for example, we might change the final D and replace it with an L yielding the pair WORL-WARL. This procedure ensures that each pseudoword is similar to its matched word in the letter being tested, in its consonant/vowel structure, and in the immediate context of the critical letter. The result was a list of 384 stimulus quadruples of the form WORD-WARD-WORL-WARL (Appendix 2).

There were four primary conditions in this experiment. Half of the trials involved the presentation of a pseudoword and half involved the presentation of a word. In half of each of those cases, the context letters were presented early, and were left on for a total duration equal to twice that of the critical letter. On the other half of the trials the strings were normally presented. Each subject saw only one member of each of the 384 quadruples, and each item was tested equally often in each condition. Sixteen subjects were run in all.

Results. The basic results of this experiment are given in Figure 14. Subjects clearly perform better on words than on pseudowords. $F(1, 15) = 23.74$, $p < .001$. There is also, for both words and pseudowords, a context enhancement effect $F(1, 15) = 25.74$, $p < .001$. Interestingly, there is only a small, non-significant interaction between these two factors, $F(1, 15) = 1.79$, $p > .1$. although the trend suggests that the enhancement effect may be slightly larger for words than for pseudowords.

In order to investigate the model's account of the enhancement effect with pseudowords, we simulated this experiment using the same parameter values, and the same sample of words used in all of our previous simulations in Part II. The sample of pseudowords were the items which were actually paired with the sample words in the experiment. With these parameters, the model did not produce a pseudoword enhancement effect. The simulation and the data showed the same pattern of results for the words and for the normal presentation of the pseudowords. The preview of the context, however, actually lead to slightly

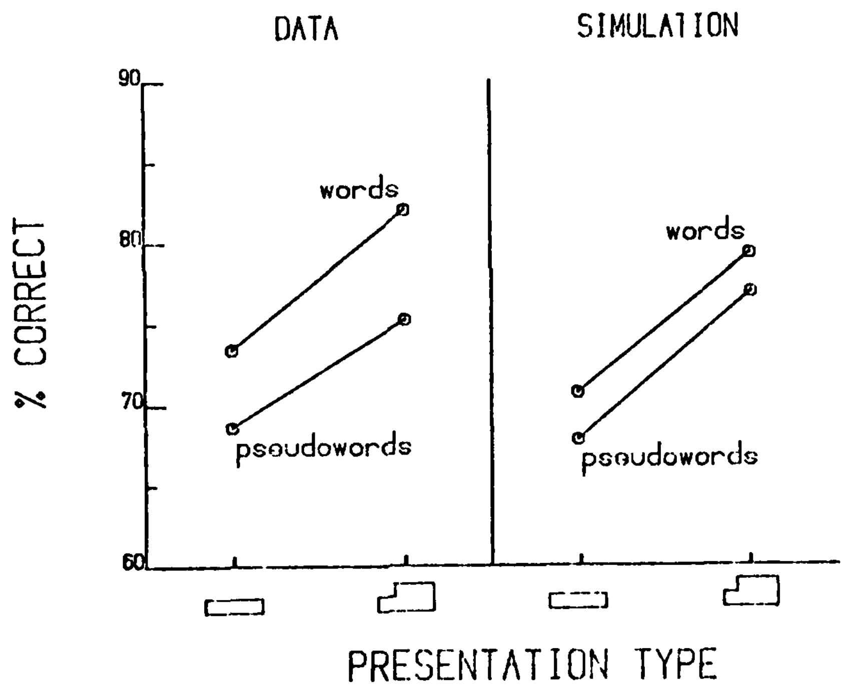

Figure 14. Percent of correct responses for words and pseudowords as a function of presentation type. Actual results are shown on the left, while the results of the simulation are shown on the right.

poorer performance on the pseudowords, averaging over all the items in the sample.

A look at the model's performance with individual items reveals large differences. Unlike the simulation of the enhancement effect for words which shows essentially the same results for each word, the pseudowords seemed to show a bimodal result. Some pseudowords showed a strong positive enhancement effect, others showed a negative effect. It would be interesting to look for these item differences in the data, but we only obtained a total of 4 trials per pseudoword in each condition, which is not sufficient to see individual item differences.

A consideration of why the simulations lead to such item differences is useful. Consider what happens when an item like TADE is used. In the enhancement condition the letters _ADE are presented early. They activate all of the words containing _ADE — words like 'made' and 'fade'. Note that none of these items will contain the critical letter, since by design the entire four letter item is not an actual word. The letters _ADE also activate, somewhat more weakly, words containing two out of the three letters _ADE, and these generally include some items like 'take' and 'tide', which actually do contain the critical letter. However, the words which match all three letters--particularly if they are high frequency words like 'made'--will inhibit these weakly activated words due to lateral inhibition at the word level. Now when the T is presented to complete the item, the 't' node faces competition from the 'm'. Moreover, as it tries to activate the words with three letters in common with it (like 'take' and 'tide'), the much stronger 'made' unit strongly inhibits them. The 't' will eventually win out, but any help that the context might have provided is more than offset by the hindrance of the previously activated items. Thus, pseudowords with one or more competitors consistent with all three letters in the context often show a negative enhancement effect. The pseudowords which show the largest positive enhancement are the ones in which the three context letters failed to match the appropriate three letters in any four letter word (e.g., W_RL).

Clearly, the behavior of our model is at variance with the facts. However, it turns out that changes in two of the parameters were sufficient to bring the simulation back into line with the data. The changes were necessitated to handle two problems which seemed to be keeping the pseudowords from showing an enhancement effect. First, words that match the three context letters are actually pushed across the threshold and produce feedback which creates strong competitors to the to-be-presented letter before that letter is even presented. Secondly, these words actually interfere with the priming of the words which could help the critical letter by lateral inhibition at the word level. This makes it very difficult for words consistent with the target to get started. To deal with these problems, it seems to be necessary to suppose that some pre-activation of word units could take place, before they began to produce feedback to the letter level and before they began to inhibit each other. Thus, the major required change was to adjust the resting levels of all words downward by .2, so that the resting levels of the highest frequency words were near -.2, and the resting levels of the lowest frequency words were near -.25. This change allows even high frequency words to be pushed a good deal above their resting level before they actually begin to cause interference. This change, in itself, was not sufficient to solve the problem of competition at the word level completely, particularly for items like TADE for which there exist very high frequency competitors consistent with all three context letters. In addition, it appeared to be necessary to keep active word nodes from inhibiting each other until their activations reached the value of +.075. With these two changes, plus minor tuning of one other parameter (the letter-to-word inhibition parameter was set to .02), we were able to provide a reasonably close account of the word and pseudoword data from this experiment and the remaining experiments to be reported in the rest of Part II.

The results of the simulation for the present experiment using the altered parameters are shown in Figure 14. The simulation results are rather close to the actual experimental results. The major difference is that the overall difference between words and pseudowords is about 2 percent lower in the simulated results than in the experiment. The size of the enhancement effect, however, for both words and pseudowords is of the appropriate magnitude. Notice that there is no interaction between the presentation type and the Word-Pseudoword variable in either case.

The changes in the parameters did not affect the model's account for the results of the experiments described previously in which only words were used. Although reducing the resting level by .2 does delay the onset of feedback, the increase in the threshold for inhibition at the word level permits more words to participate in the feedback. Below we will consider the effects of these changes on the results of the simulations reported in Part I.

Experiment 8

We found in the previous experiment that 'good' pronounceable nonwords lead to results which, although poorer overall than words, do show essentially the same pattern of interaction with context as with words. Suppose we had presented poor nonwords whose statistical structure did not match that of English very closely, would we still get the enhancement effect? To address this point, Experiment 8 was identical to Experiment 7 except for the fact that the nonword stimuli were constructed in a different way. In this case, the nonwords were made by a transformation of the letters of the actual word. In particular, for any word, its nonword mate was constructed by reversing the order of the first and second letters and the third and fourth letters. Thus, if the original order of letters was 1-2-3-4, the new order would be 2-1-4-3. For four letter words beginning with consonants this leads to an unusual string of letters, often unpronounceable. For example the new quadruples containing the words WORD and WARD would contain the nonwords OWDR and AWDR.

The basic results from this experiment are shown in Figure 15. In order to maintain the same average percent correct, the durations had to be increased over those in the previous experiment with the resulting higher percent correct for the words. Even then, the performance on the reversed words was somewhat poorer than the 'good' nonwords of the pre-

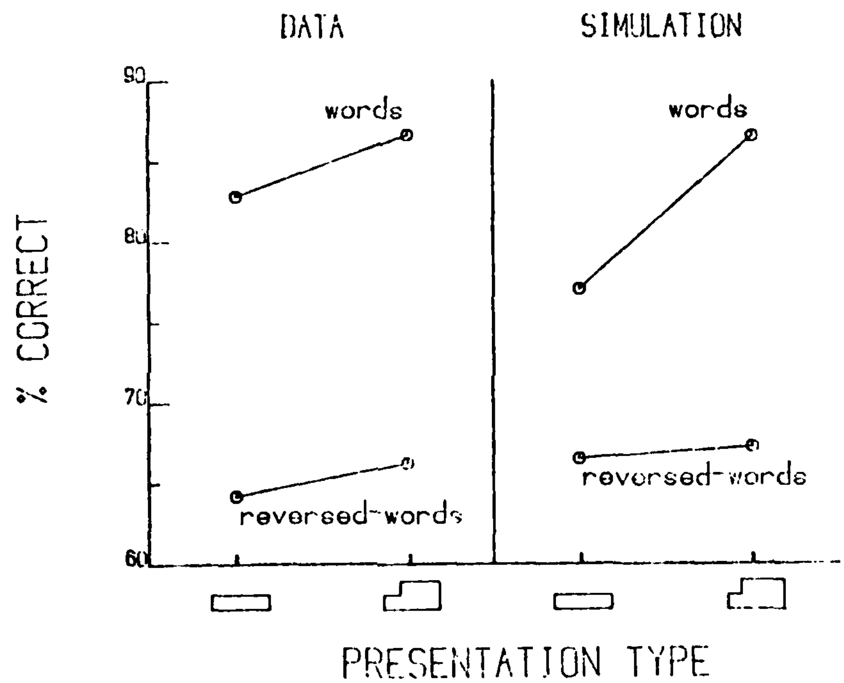

Figure 15. Percent of correct responses for words and reversed words as a function of presentation type, from Experiment 8. Actual data are shown in the left panel, the results of the simulation on the right.

vious experiment. Probably due to the restriction of the range, the enhancement effect on words was somewhat reduced over our other experiments. Nevertheless, it was highly significant, $F(1, 15) = 8.672$, $p < .001$. The enhancement effect for these 'poor' nonwords, on the other hand, is much smaller and non-significant, $F(1, 15) = .747$, $p > .5$.

The sample of items used in the simulation of our previous experiments was extended by taking each pair of words and generating a pair of nonwords by reversing the first two letters and the last two letters. The results of these simulations are illustrated in Figure 15. The simulation does not appear to be susceptible to the ceiling effect which apparently reduced the magnitude of the enhancement effect on words in this experiment: The simulation produces just about the same size enhancement as it did in previous cases. What is clear for both the simulation and the data is that neither produce much facilitation for the reversed words.

Experiment 9

Whether an item is a word or not is a matter of fact, but whether or not it is a pseudoword is a matter of theory. According to some views, an item is a pseudoword if it conforms to (an unfortunately undefined) set of "orthographic rules". According to others, an item is a pseudoword if it is pronounceable. On our theory, an item is a pseudoword to the extent that it shares a number of letters in the same positions with actual English words. Clearly, on this definition, the "goodness" of a pseudoword is a matter of degree. The goal of this experiment was to determine whether pseudowords varying in their similarity to words in English would vary in perceptibility and in susceptibility to the contextual enhancement effect.

The goal was to get a set of stimuli all of which were all at least marginally pronounceable and orthographically regular, but which differed in their similarity to the words of English. In order to do this a simple grammar of the four letter words of English was constructed and the "set of possible four letter words" of English were generated. Following this, the actual words of English were culled out by removal of all strings from the list which appeared in the Kucera and Francis word count and all other strings recognizable as words. The measure of similarity to words in English was based on the sum of the conditional probabilities of each letter given both the preceding and following context, according to the following equation:

$$V_i = p(L_1) + p(L_2|L_1) + p(L_3|C_1L_2) + p(L_4|C_1C_2L_3)$$

$$+ p(L_4) + p(L_3|L_4) + p(L_2|L_3C_4) + p(L_1|L_2C_3C_4) \quad . \qquad (2)$$

L_j represents the jth letter of the string V_i, C_j represents the class (i.e. whether the letter was a consonant, a vowel, or a final E) of the jth letter of the string. The expression $p(A|B)$ represents the proportion of word types containing letter A in the appropriate position, out of those ending in pattern B. Items were counted as words only if they occurred at least 5 times per million in the Kucera-Francis word count. The equation gives one measure of the degree to which we might expect string V_i to be in the language, based on the conditional probabilities of occurrence of the letters in similar contexts.

Once values were assigned to all of the strings, the strings were ordered from best to worst. Quadruples of strings were then constructed so that there were two strings high in this value that differed by one letter, and two strings low in this value that differed by the same letter. A total of 384 such quadruples were generated, 96 for each of the four serial positions. The list of stimuli are given in Appendix 3.

As in the previous two experiments, 16 subjects were run on a 2x2 design in which one factor was whether the string was high or low in our measure and the other factor was whether or not the context letters preceded the critical letter. As before, in the enhancement condition the ratio was held at 2:1.

The basic results for this experiment are given in Figure 16. Clearly, not all pseudowords, not even all pronounceable pseudowords, are equally perceivable. The 'good' pseudowords showed substantially better performance than the 'poor' ones, and the difference is marginally reliable, $F(1, 15) = 4.19$, $p < .07$. Both kinds of words seemed to show an improvement with a preview of the context. The effect was highly significant for the good pseudowords, $F(1, 15) = 24.94$, $p < .001$, but only marginal for the poor items, $F(1, 15) = 4.30$, $p < .06$. Importantly, the 'poor' pseudowords showed a substantially smaller enhancement effect than 'good' pseudowords. The interaction evident in the Table was significant. $F(1, 15) = 5.70$, $p < .05$.

In order to compare our model with this experiment, a sample of items was drawn from the new list of items used in the experiment. A

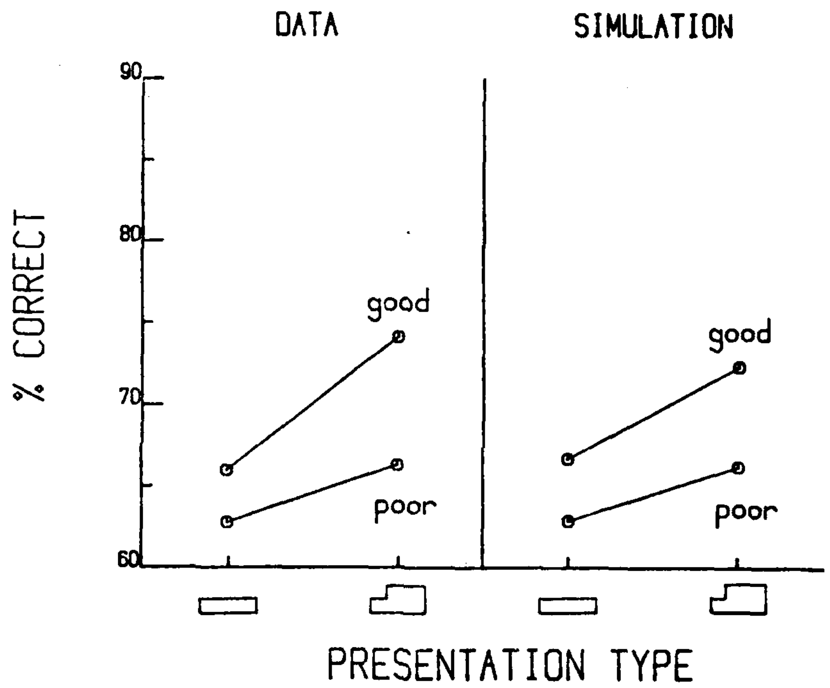

Figure 16. Percent of correct responses for good and poor pseudowords as a function of presentation type. Actual data are shown in the left panel, and the results of the simulation are shown on the right.

total of 40 quadruples of words were chosen at random, 10 for each serial position. In the simulations, we used one 'good' and one 'poor' pseudoword from each quadruple. Employing the same parameter values as in the two previous simulation runs, with a basic duration of 12 time cycles, we obtained the results shown in the Figure. A comparison with the actual data indicates that the model comes pretty close to the data. Clearly, the measure used to define the 'good' and 'poor' pseudowords is sensitive to those variables which both determine the overall level of performance on nonwords and the magnitude of the enhancement effect in our model.

Summary of Enhancement Results

In the previous several sections we reported a number of results concerning the interaction of the timing and quality of the available contextual information on the perceptibility of target letters. We showed that the perceptibility of a target is strongly dependent on the amount of information presented about the context letters. The more contextual information the better the perception. It should be kept clearly in mind that the contextual information improved performance *even though it could in no way help choose between the alternatives from which the subject must choose*. Thus, the context must affect processing prior to the termination of the presentation and the onset of the forced-choice alternatives.

We also showed that the usefulness of the contextual information was much enhanced when it came *early* in the interval, before the critical letter was to be presented.

We also demonstrated the enhancement phenomenon with pseudowords as well as words. Clearly, presenting early contextual information is not merely helping words, it also helps nonwords which are similar to words. In fact, the more word-like they are the larger the enhancement effect.

Importantly, we showed that the same model which accounts for the results of Part I also accounts for the pattern of results obtained in this entire set of experiments. Only those experiments involving enhancement of pseudowords required any modification of the parameters.

Can the results of all of the experiments we have simulated be accounted for with the revised parameters used to account for the pseudoword enhancement effect? To address this question, we reran a sample of items from each of the previous experiments (those described in both Part I and Part II of the paper). We found that the model continued to produce qualitatively the same results for all but one of our previous simulations. We found that the addition of the +.075 threshold prior to interaction within the word level caused the model to generate a bigram frequency effect of about 5 percent for pseudowords, whereas McClelland and Johnston, 1977, found a negligible affect of this variable. The reason for this would appear to be that pseudowords with high frequency bigram transitions tend to have a larger number of weak friends than do pseudowords low in bigram frequency. If all of the items are inhibiting each other, as with the previous parameter values, there is no net effect of bigram frequency on performance. The existence of more items is canceled out by more inhibition. The addition of the threshold before which items can feed back, but not inhibit each other, gives the advantage to the high bigram frequency pseudowords.

It is not clear what more should be said about this discrepancy. It is possible that there are compensating changes that could be made in other parameters which would allow the model to accommodate all of the findings simultaneously. Alternatively, differences in the way subjects set various parameters of their perceptual systems from situation to situation might account for the discrepancy. We have already found it useful to assume that subjects have control over the letter-to-word inhibition parameter; perhaps it will turn out that they have control over the placement of the threshold for interaction among units at the word level as well.

Overall, then, the model has accounted for a wide range of findings with the same parameters. Certain of the findings with the perception of pronounceable pseudowords require us to assume that subjects have some control over at least one of the parameters of the perceptual system, and it is possible that they have control over other parameters as well.

Serial Position Effects

One problem which was raised in these experiments which is not addressed in our model is the effect of serial position. For the most part serial position plays a minor role in the processing of word stimuli and therefore, for the sake of simplicity, we have ignored it. However, in the case of the enhancement paradigm it appears that serial position effects are magnified by some sort of "outside-in" processing strategy which leads to variations in performance due to serial position.

There are at least two possible ways of accounting for serial position effects within the framework of our model.

(1) The quality of the information at the ends of the words might be better than the quality of the information about letters internal to the word due to lateral interference (Eriksen & Rohrbaugh, 1970; Estes, Allmeyer & Reder, 1976) or focus of attention. In our model, the effect of stimulus quality manipulations is to influence the rate of activation of feature level units by the input; the higher the quality of the input the faster it drives the relevant feature node toward its maximal activation level. In all of the simulations we have presented thus far, we have assumed a fixed rate of input, independent of serial position.

(2) It may be that not all letters are read-out simultaneously. In all of the simulation results reported, we have assumed that all letters are read-out simultaneously at the point at which, on average, optimal performance will be achieved. It is, of course, possible that different serial positions are read out at different times--perhaps because the readout process is a resource demanding process controlled by attention.

Since we found that we could account for the general pattern of results in the experiments we have evaluated without any of these assumptions regarding the effects of position, we chose not to include any of these possibilities in the simulations reported thus far. In this section we show that implementation of these possibilities in our model allows us to account for some of the effects of serial position, and their interaction with context timing conditions.

First we examine the effects of serial position for standard and enhanced conditions with word stimuli. It turns out that the major trends in these curves can be accounted for solely by supposing that the input rate is higher for some letters, particularly the first letter, than it is for others. The data base used came from the standard and enhanced word conditions of Experiment 7 and from like conditions run in another experiment, not described above, which used the same stimuli. The serial position curves are illustrated in the left panel of Figure 17. These data show a bow-shaped serial position curve under standard conditions and a relatively flat serial position curve under enhanced conditions. The normal parameters used in the original simulation of Experiment 7 produce the serial position curves of the central panel of the Figure. However, if we differentially weight the inputs to each of the four serial positions (giving the positions relative rate parameters of 1.6, 1.15, .85 and 1.05 respectively), we get the serial position curves shown in the right panel of the Figure. Clearly, the results of the simulation capture the major features of the observed data. Interestingly, the differential weights give the normally presented words the bow-shaped serial position curve as we would expect while retaining the flat serial position curve for the enhanced presentations. The reason for this appears to be that the perceptibility of the letters in the enhanced condition is relatively more dependent on contextual information and less dependent on the direct information about that letter. The letters with the weakest direct input get the most help from the other letters, and vice versa. Note that this account makes no claim as to whether the different rates of activation are due to attentional variation or lateral interference on the central letters. We simply assume that information comes at differential rates to the different positions.

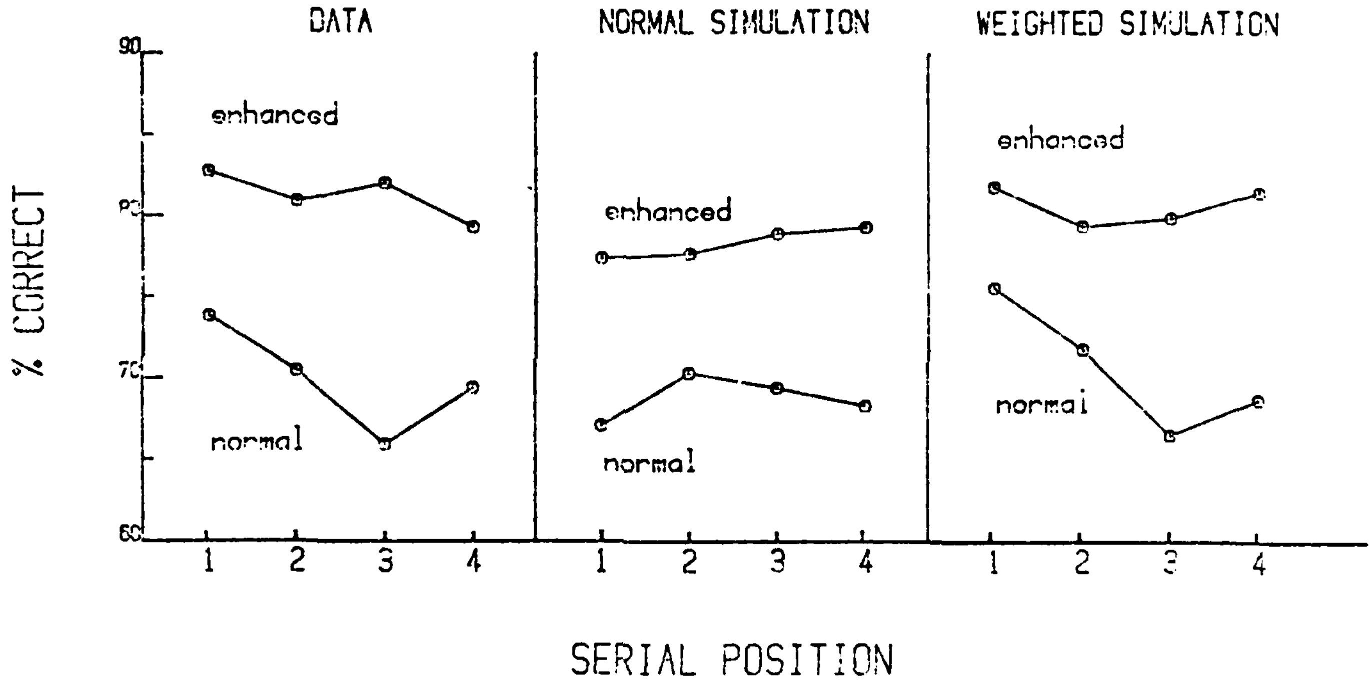

Figure 17. Interaction of serial position and enhancement effects. The left panel shows data from the word trials in Experiment 7 combined with data from similar conditions of an experiment not reported here. The center panel shows the results of a simulation run using standard parameters. The right panel shows the results of a simulation run in which the input strength varied across serial position.

The mechanism just described does not successfully account for all of the serial position data from these experiments. It does not account for the way serial position varies as a function of whether the target precedes, follows, or is simultaneous with the context. To account for these results, we combined the assumption of differential activation rate discussed above with the assumption that order of read-out varied from position to position. Specifically, we assumed that the end letters are readout first, followed by the second letter and then the third. The results of this simulation are shown in Figure 18. A comparison with Figure 7 shows that we have captured the general features of the serial position curves, although the fourth serial position for the context first condition shows much better performance than we find in the actual data.

In addition to these two possible mechanisms, there are several other factors which might be contributing to serial position effects. These include perceptibility differences of the particular letters which happen to occur in the different positions, statistical properties about the words in the language with particular letters in particular positions, variations in locus of fixation and attentional strategy as a function of experimental conditions and instructions, and so on. Since both of the mechanisms we have described are potentially subject to attentional control, it may well be difficult to gain control and definitive understanding of these mechanisms until the factors which govern control of attention are understood. For these reasons, we feel it may not be worthwhile to try to track down every aspect of the serial position effects we have observed at this stage. The mechanisms we have

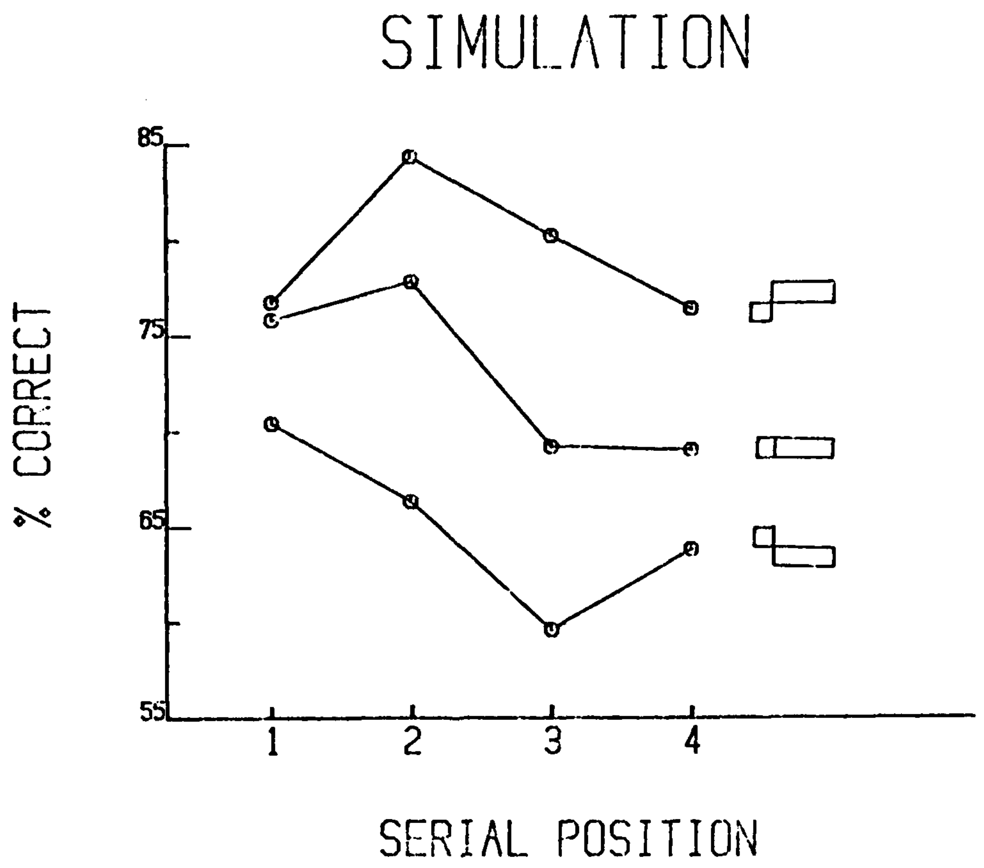

Figure 18. Simulated serial position curves for the context first, target first, and simultaneous presentation conditions used in Experiment 3.

suggested seem to be capable of accounting for the general trends in the serial position data in a relatively straightforward manner, however, and so may be worth further consideration in later research.

Relating Retinal Position to Position in a Word

Until this point, we have completely ignored the fundamental problem of how visual features which are initially registered by receptors in particular locations on the retina are mapped into the four letter slots in our model. This is not a trivial matter since it is possible for us to read words in print of various sizes, in any position on the retina provided only that the resolution is sufficient. Hinton (Note 1) has recently proposed a general scheme which employs interactive processing of the general sort we have outlined here to carry out the whole range of transformations which might be involved in such a mapping. These include rotation (in three dimensions), translation (also in three dimensions) and size adjustment. The basic idea is that each possible mapping is associated with a unit that modulates the extent to which a particular feature of the retinal display activates a particular unit in the cannonical activation network for perception of patterns. In our case, for example, these mapping units would determine to what extent features in a particular location in the retinal array would activate units for features in particular positions relative to the beginnings and endings of words. Initially, each possible mapping is open, but as processing continues the mappings which are most consistent with some stable higher-order perceptual structure are strengthened and come to dominate all of the other mappings, thereby effectively closing all the activation paths associated with all the other mappings. One implication of this notion is that information about position and information about the identity of letters may become separated in the perceptual system if the set of retinal features for a particular letter end up being mapped onto the right set of cannonical features but in the wrong cannonical position. In fact, experiments using the full report or probed report procedure show that subjects often rearrange letters in their reports, indicating that they have picked up the identity of the letters shown without necessarily picking up their order (Estes, 1975; McClelland, 1976).

We have not attempted to incorporate Hinton's ideas fully into our model, but we have given some thought to the possibility that there might be some tendency for information presented in one location to activate detectors in a range of locations, rather than just simply in one fixed positional channel. Perhaps there is a region of uncertainty associated with each feature and with each letter. If so, a given feature in a given input position would tend to activate units for that feature in positions surrounding the actual appropriate position. As a result, partial activations of letters from nearby positions would arise along with the activation for the letter actually presented in a particular position. Similarly, this same input might partially activate word units for words with that letter in neighboring positions. In a scheme such as this, the role of feedback from higher levels would be not only to reinforce letters consistent with some known pattern or combination of known patterns, but also to reinforce the activations of these letters in particular positions at the expense of other positions. It should be clear, then, how this scheme could cause transposition errors, especially in those cases where the transposition makes a more word-like string than the original (e.d., RAED -> READ).

A mechanism of this type would have the property of "smearing" the pattern of activation produced by a stimulus of one length out over a somewhat longer array of possible positions. One side-effect of such smearing would be that it would tend to produce activations of words of other lengths beside those corresponding to the actual length of the input. Such activations could, of course, generate feedback, supporting the letter-level activations which got them going. Such support could be very valuable, especially to the perception of pseudowords. Such support would make performance on pseudowords less dependent on the details of the set of four letter words and in that sense, more robust.

The scheme outlined above has not yet been incorporated in our simulation model. We believe, however, that a scheme of this sort could be made to fit into the present theoretical framework, and would offer a plausible account for the findings that illegal nonword strings are often seen with letters transposed if the transposition will produce legal strings (Estes, 1975a; c.f. experiment by Stevens reported in Rumelhart, 1977).

Some Extensions of the Model

In the previous sections of this paper, we have focused on producing accounts of the perception of letters in the context of words and pseudowords. However, the modeling framework we have been working with is potentially much more general than this. At the outset, we proposed a more general framework for the processing of words and pseudowords in either the visual or the auditory modality. Figure 19 (Figure 1 from Part I) shows the general view with which we began. Here we have, in addition to the visual processing system, a speech processing system, including an acoustic feature level and a phonological level. The Figure also provides for input from higher contextual levels.

In this section we discuss a number of results which we believe could be accounted for with an extended version of our model, incorporating the processes represented in Figure 19. To begin, we discuss the role of prior linguistic context in visual word recognition, and the interaction of information derived from linguistic context and information from a visually presented preview of the word presented in parafoveal vision. Then we show how our model can be extended to account for some recent data from word pronunciation experiments. Here the focus is primarily on how the letter and word levels interact with the phonological level to produce pronunciations for words and pseudowords. Finally, we consider the application of our model to speech perception. There are a number of phenomena which have primarily been observed in speech perception contexts which appear to require the kinds of processes we have been exploring in our model.

Before turning to these sections, however, we want to make it clear that these extensions have not yet been incorporated into a working version of our simulation model. Thus, we cannot say for certain exactly how the model would behave in simulating these phenomena, nor how

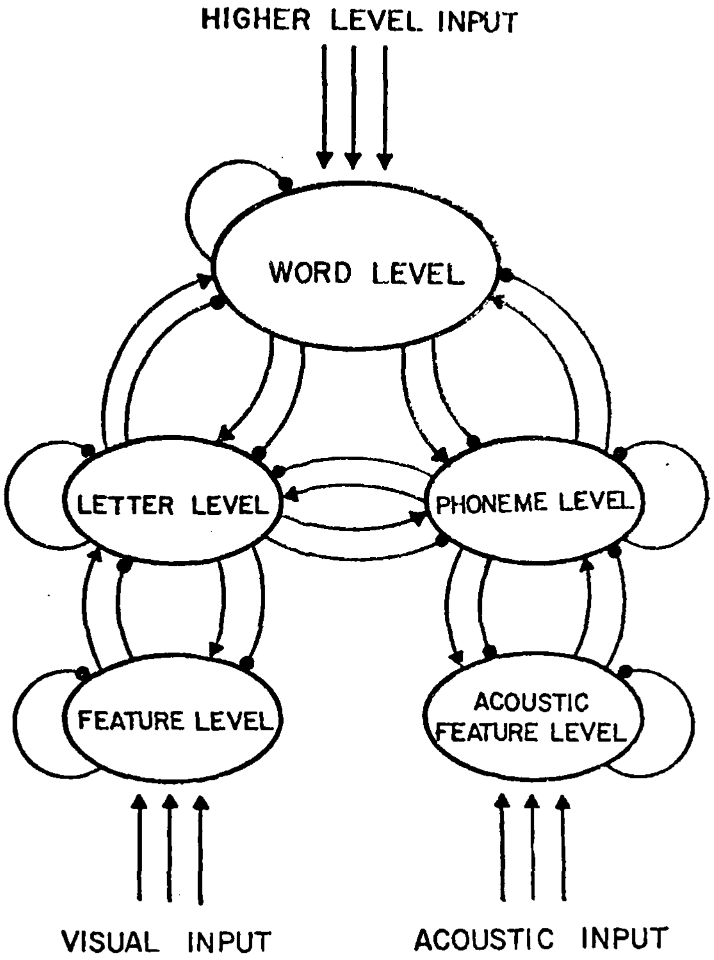

Figure 19. Full version of the interactive activation system for visual and auditory word recognition.

details of the model might influence these simulations. However, some of the basic phenomena are quite simple, and many are at least qualitatively consistent with general characteristics of the model. Thus, it seems likely that an exact simulation of these phenomena could be formulated.

Use of Context in Word Recognition

It is, of course, a well known fact that context preceding the visual presentation of a word can influence identification of the word. Tulving and Gold (1963) demonstrated this, using contexts such as:

Far too many people today confuse communism with _____.

The presentation of the context was followed by a brief tachistoscopic flash of the word. When the word socialism was shown in this context, probability of correct identification was greatly increased, compared to the presentation of the same word alone. When the word raspberry was shown in this context, probability of correct identification was greatly reduced. A subsequent study by Tulving, Mandler, and Baumal (1964) further extended these findings, examining the effect of varying amounts of prior context in conjunction with variations in the quality of the visual information (i.e., the duration of the tachistoscopic presentation).

The results of these experiments have been accounted for by the logogen model of Morton (1969). Our model is quite like the logogen model in various ways, as we pointed out in Part I, and it is clear that it would account for the basic facilitation and interference effects of appropriate and inappropriate context. As in the logogen model, we would simply imagine that a context would tend to prime the nodes for words consistent with it. Such words would tend to benefit from this priming. The interference with performance for words inconsistent with the context could be accounted for in various ways. One possibility is that the contextual inputs directly inhibit the nodes for words not consistent with the context. This direct inhibition may not be necessary to account for the effect, though it will be relied on somewhat later in this section. Our model does provide for two other sources of interference. In our model as it stands, priming of one set of words would result in relative inhibition of nodes for other words, due to the lateral interference mechanism, provided the context was strong enough to drive the activations of nodes for contextually appropriate words above the interaction threshold. Furthermore, the process of selecting a response takes into account the strengths of all of the logogens, and active logogens other than the correct one have the effect of reducing the probability that the correct response will be chosen.

Since we have considered performance in Reicher's forced-choice paradigm so extensively, it seems appropriate to comment on the effect of linguistic context on performance in this paradigm. Though there are no published studies on these effects, there are two unpublished findings. One of these comes from a study by Johnston (personal communication). He compared forced-choice performance for letters in words when the presentation was preceded by a context sentence similar to those used by Tulving and Gold. On half the trials, the item shown was appropriate to the context, on the other half, it was a word differing by a single letter from a word that would fit. The subjects task was to choose between the two alternatives. For example, one of the sentences might have been:

I like to follow and I hate to ... .

For this context, the word pair might have been LEAD-LEND. The results of the experiment were that the context had a large effect biasing performance in the direction of the contextually appropriate word, but it did not have a reliable effect on the average probability correct, compared to a condition in which the same items were presented with no preceding context. The other piece of data comes from an unpublished experiment by one of us (Rumelhart). In this study, stimulus triples consisting of a prime word and two target words, both semantically related to the prime and differing from each other by a single letter, were used (e.g., WAR—ARMS-ARMY). As in the Johnston experiment, the prime was followed by a brief, masked, presentation of one of the two alternatives, and this was followed by a force choice between the differing letters. Also, as in the Johnston experiment, there was hardly any overall effect of the prime on accuracy, compared to a control condition with an inappropriate prime. This time accuracy improved a little bit when an appropriate prime was used, but the difference was only 2% in the forced choice, and it was not significant.

Unlike the other findings discussed in this section, we have actually run simulations of these two experiments, albeit rather informal ones. To simulate the effects of the prime, we simply imposed a constant input to one or more word nodes as appropriate, and left it on for a few cycles until the activation of the node stabilized. Then, we presented the target stimulus to the model as before. We found that when the prime pre-activated only one word (e.g., LEAD, as in the example of a possible sentence from the Johnston experiment), there was a considerable bias toward choosing the forced-choice alternative letter consistent with the primed word. This bias helped performance on those trials when LEAD was actually shown to the model. But it had an equal effect in the opposite direction when LEND was shown. When the prime pre-activated both choice alternatives, there was only a very slight effect—as in the actual data, there was a small benefit, which did not grow larger than about 2% even with a very substantial prime.

Effects of context have also been found on reaction time measures of performance, particularly in the lexical decision task (Meyer & Schvaneveldt, 1971; for a recent review see Spoehr & Schuberth, in press), but also on the time it takes to name a word aloud (Meyer, Schvaneveldt, & Ruddy, 1975). To account for such effects, we might imagine that responses based on the activations of word nodes are triggered in such tasks when the activation of a particular word node reaches some threshold activation value. In such a case, a related context could give the node for a particular word a head start over other nodes, thereby reducing the time it would take for activation based on stimulus information to drive the activation of the logogen beyond the threshold level.

Studies of the effect of context in reaction time tasks have revealed some interesting interactions, which seem to be consistent with our model. First of all the model can easily account for the well-known finding (Meyer, Schvaneveldt & Ruddy, 1975) that the effect of context is greater when the stimulus information is of lower quality. In the model, the effect of related context is to reduce the distance from the base activation level of the correct word node to the response threshold. The effect of reducing stimulus quality is to slow the rate of activation of the correct word node (this would happen indirectly, as a result of slowing the rate of activation of nodes at the feature and letter levels). The two effects combined produce the interaction because the effect of the prime makes more of a difference when the bottom-up activation is accumulating at a faster rate (McClelland, 1979).

The effects considered thus far can be explained without invoking many of the more complex features of our model. However, a recent finding of McClelland and O'Regan (in press) seems to require some of the features of our model which have not been considered in other models of visual word recognition. McClelland and O'Regan investigated the joint effects of sentence contexts and a parafoveal preview of a word on reaction time to name the word when it was later presented at the point of fixation. Subjects read a sentence context, then initiated a sequence of displays consisting of a fixation point followed by a preview stimulus lasting 100 msec and centered about 1.5 degrees to either the right or left of fixation. This preview was followed 100 msec later by a target word in the same location as the preview. The contexts were either completely neutral ("The next word will be ..."); weakly constraining ("For breakfast I like ..."); or strongly constraining ("I like coffee with cream and ..."). In the latter two cases the target word always fit the context. The preview stimulus consisted of either the exact target word (e.g., sugar); a distortion which preserved the end letters and the outline shape but altered some of the internal letters (sngcr), or a row of x's (xxxxx). The results are shown in Figure 20. Overall, the strongly constraining context produced faster reaction times than the weakly constraining context, and the weakly constraining context produced faster reaction times than the neutral context. In addition, the word preview produced faster times than the same shape preview, and this preview produced faster times than the row of x's. However, there was a highly significant interaction of context and preview information, as indicated by the box. It appeared that a weak context, followed by a completely uninformative preview, produced no benefit compared to the neutral context followed by the x's preview. At the same time, the shape and end letters preview produced no benefit compared to the x's preview when the context was neutral. However, the <u>combination</u> of the shape and end letters preview with the weakly constraining context was enough to produce a reliable facilitation over all three other conditions in the box. Thus, it appears that two sources of information, each of which is insufficient by itself to produce facilitation, can nevertheless produce facilitation when combined.

To account for these effects McClelland & O'Regan (in press) suggested both the shape and end letters preview and the weakly constraining context could be producing spurious interfering activations along with beneficial activations of the node for the correct word. For example, the context,

For breakfast I like ______.

might activate the node for the correct word (which is 'fruit'), along

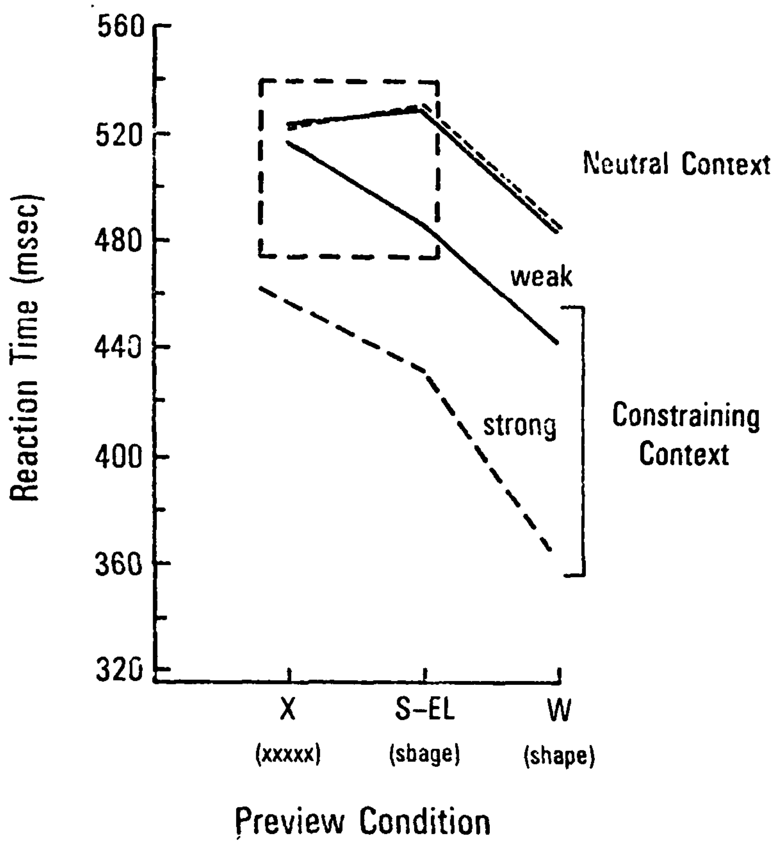

Figure 20. Effects of context and preview information on time to name a target word. W stands for the word preview condition, S-EL for the preview condition in which the shape and end letters of the word have been preserved, and X for the condition in which the preview was simply a row of X's.

with several other nodes, such as 'cereal', 'eggs', 'juice', 'coffee', and others. The activations of these other nodes could inhibit the node for the correct word, thereby canceling the benefit it would have gotten from context. By the same token, a shape and end letters preview of the word fruit, say fnust might activate nodes for several incorrect words (including, for example, 'frost', 'first', 'fleet', etc.) as well as the correct node. Again these activations could produce inhibition which would tend to cancel the benefit the 'fruit' node would have gotten from context. But note that, in general, the set of items consistent with the context and the set of items consistent with the preview only contain one member in common, namely the actual correct target word. Thus, McClelland and O'Regan reasoned, if the context inhibits nodes inconsistent with it as well as exciting nodes consistent with it, and if the preview inhibits nodes grossly inconsistent with it while exciting those partially consistent with it, then the context and the preview will tend to cancel each other's spurious activations, driving them below a competition threshold, and leaving only the activation of the target word above threshold. The combination of the two sources of input would thus combine the benefits of each without incurring the costs of either. In this way, the two ineffective inputs might work together to pinpoint the correct word and facilitate naming it.

We have not simulated this interpretation, but it clearly relies on features of our model which are not typically stressed in other models of word recognition, namely a) competition between active units and b) a threshold activation level, below which competition ceases.

Pronouncing Words and Pseudowords

Glushko (1979) has recently carried out a set of experiments in which he measured pronunciation latencies for different words and pseudowords. The basic results found by Glushko and others concerning pronunciation latencies seem to be consistent with a natural extension of the model. First, we will review the basic findings on word and pseudoword pronunciation and then show how we believe our model could be extended to account for these results.

Prior to Glushko's work, there were two basic findings to be accounted for:

(1) Words are pronounced faster than pseudowords (e.g. Forster & Chambers, 1973; Frederiksen & Kroll, 1976).

(2) "Exception words", such as PINT, which are not pronounced according to the typical spelling to sound patterns of English, are pronounced more slowly than regular words, such as PINK, which are pronounced according to the rules of English (e.g. Baron & Strawson, 1976, Gough & Cosky, 1977; Baron, 1979).

These two results had served as a cornerstone of the view that word pronunciation involved two separate mechanisms. They could be pronounced by rule, such as the case with pseudowords, or they could be pronounced through a lookup mechanism in which a pronunciation stored with the words could be accessed and used. This second mechanism was assumed to be necessary in the case of 'exception words.' Regular words could be pronounced either way and thus, since there were two access routes, were pronounced more quickly. Glushko has argued against this "two-mechanism" approach and in favor of a "one-mechanism" approach in which both words and pseudowords are processed identically by the same mechanism. In his view, "...as letter strings are identified, there is parallel activation of orthographic and phonological knowledge from a number of sources in memory. A pronunciation is generated using procedures for determining how to modify the activated information in order to synthesize the desired articulatory program." We can interpret Glushko's proposal in terms of our model as represented in Figure 19. Visual input enters the system and activates a set of features as usual. The features in turn activate the relevant word and letter level units, each feeding back inhibition and excitation as usual. In addition, we imagine that each activated word activates its representation at the phonological level. These phonological units, of course, in turn feed back to the word level just as the letter level units do. At the same time, we can imagine the letter units feeding directly into the phonological level activating the typical phonological units associated with those letters. As some point a stable pattern of activity will be established at the phonological level and a pronunciation can be generated.

It should be clear from this how our model would account for the two results mentioned above. Consider first the word-pseudoword pronunciation latency differences. To be concrete, let's consider the processing involved in the processing of the strings PINK and BINK. Now when PINK is presented it will, of course, activate a set of letter units which, in turn, will activate a number of word units. In this case, the words 'link', 'mink', 'pink', 'rink', 'sink', and 'wink' would all be activated. The word 'pink' would be activated most of all. These words would then each activate the relevant phonological units at the phonological level. Of the relevant phonemes the /p/, /m/, /l/, /r/, /s/, and /w/ would all be activated in the first position, but the /p/ most strongly. In the remaining positions the /i/, /ng/, and /k/ would be activated by all words. Each of these phonological units would in turn feed back into the word level further strengthing words with these patterns of pronunciations. Very soon, a stable pattern of activations would appear at the phoneme level and a pronunciation could be generated. Now consider what would happen when the pseudoword BINK is presented. Upon its presentation no single word develops a strong activation, instead, a number of words are activated about equally. In this case, they include the words 'bank', 'bind', 'bing', 'bunk', 'fink', 'link', 'mink', 'pink', 'rink', 'sink', and 'wink.' Clearly, the /b/, /i/, /ng/, and /k/ units would eventually get the most activation and the pronunciation could be made. There would, however, be much more competition among the various possible pronunciations and the time to pronounce the pseudoword would be slower than the time to pronounce the word.

Consider now the latency difference between regular words like PINK and irregularly pronounced words like PINT. We have already seen that on the presentation of a regular word like PINK the set of activated words all agree with regard to the pronunciation of the majority of the phonemes, thus leading to relatively rapid pronunciation. But, consider what happens with PINT. Upon presentation of PINT the words 'hint', lint', 'mint', 'pine', 'pink', and 'pint' are all activated. Note, in particular, that two vowels will receive a rather high degree of activation, namely the units for the phonemes /i/ and /I/. Thus, there is a good deal of competition and in fact, we might expect the incorrect pronunciation -- /p/ /i/ /n/ /t/ -- rather than the correct -- /p/ /I/ /n/ /t/ -- to be given some of the time. According to this account, it is this increased competition, not the application of spelling to sound rules, which accounts for the advantage for regular words. Words are regular not by virtue of their correspondence to any set of abstract rules, but rather by virtue of the fact that visually similar words receive similar pronunciations.

Glushko has found a reasonable amount of evidence for his view that the construction of a phonological code for a word or non-word is influenced by the activations of phonological codes for known words. In this type of account, regularity is determined by the consistency of the pronunciations of the words activated by a particular string. Given this notion of regularity, we should expect to *find* a category of exceptional or irregular pseudowords as well as exceptional words. To test this, Glushko chose a set of pseudowords such as BINT which are very similar to exception words and compared the time to pronounce these exceptional pseudowords to the time to pronounce regular pseudowords like BINK. He reasoned that BINT would activate the set of words 'bent', 'bind', 'bunt', 'hint', 'lint', 'mint', and 'pint'. The words 'bind' and 'pint' would activate the (irregular) /I/ unit while the words 'hint', 'lint', and 'mint' would all activate the /i/ unit. This competition should make BINT slower than BINK. Indeed this is just what Glushko found. This result would seem to be very difficult to reconcile with the two-mechanism view in which all pseudowords are presumably pronounced by rule. It seems very consistent with Glushko's view that pronunciation makes use of a synthesis of activations of stored pronunciations. Our model seems to provide the obvious formalism for modeling such processes.

If regularity is not defined in terms of conformance with spelling to sound rules, but with consistency of pronunciation among a set of words which mutually activate each other, there should be words which are pronounced regularly, but which are slow to pronounce because of the existence of high frequency similar words which have a different pattern of pronunciation. Thus, a word like WAVE should take more time to pronounce because of the existence of the word HAVE which is pronounced with a contrasting vowel sound. Indeed, Glushko found just this effect. Words from inconsistent neighborhoods are pronounced more slowly than those from consistent neighborhoods. Again, this result is clearly difficult to explain in terms of the two process model, but falls out immediately from an approach like Glushko's.

Obviously, we haven't yet shown that our model will actually produce the effects we have just argued that it will. It is not altogether clear, for example, whether we can get away with the letter level to word level to phonological level pathway as the only way of producing pronunciations or whether the letter level to phonological level route is essential. We obviously will not be able to answer this question until the simulation model has actually been constructed and simulation runs can be made. At this point, all we can really claim is that our model appears to be extendible to the case of word and pseudoword pronunciations, and appears to be consistent with a very important body of results for which no well specified model exists.

Extension of the Model to Speech Processing

The processing structure we have explored in this paper may have general utility in modeling other psychological phenomena beyond those concerned with the perception and pronunciation of visually presented words. One very promising extension of the model would be into the area of speech perception.

The role of context in speech perception is of course very well established. Foss and Blank (1980) have recently reviewed four major phenomena illustrating the role of context.

(1) Phoneme Monitoring. The time it takes subjects to press a key indicating that they have detected a particular phoneme is influenced by the predictability in the context of the word containing the target phoneme (Morton & Long, 1976). For example, it takes less time to respond to the b in book than it does to the b in bill in the following context:

> He sat reading a book/bill until it was time to go home for his tea.

(2) Shadowing. When shadowing speech with deliberately inserted mispronunciations of words, subjects quite often restore the "correct" or "intended" phoneme, even though what they are shadowing does not in fact contain that sound (Marslen-Wilson & Welsh, 1978). This is true even when subjects are given the instruction to shadow verbatim. Typically these restorations occur without any pause or hesitation, and in many cases subjects seem to be completely unaware that there is a mispronunciation. Two contextual variables seem to influence the probability that restoration will take place, namely the position of the target mispronunciation in the word, and the predictability of the word from context. Mispronunciations in highly predictable words are much more likely to be restored than mispronunciations in less predictable words, and mispronunciations in the latter portions of words are much more likely to be restored than mispronunciations at the beginnings of words.

(3) Detection of Mispronunciations. Even when listening to speech specifically with the instruction to detect errors, subtle mispronunciations may be extremely difficult to detect, especially

when the mispronunciation occurs late in a word (Cole, 1973; Marslen-Wilson & Welsh, 1978). While some of these effects might be attributable to lateral masking, it appears unlikely that all of them can be (Foss & Blank, 1980).

(4) Phonemic Restoration. Even more striking still than the fact that mispronunciations may pass unnoticed even when we are listening for them is the finding that subjects can restore whole excised phonemes when they are replaced by a noise, a cough, or a tone (Warren, 1970; Warren & Obusek, 1971). A recent series of studies by Samuel (1979) has demonstrated that restorations are more likely when words occur in semantically predictive contexts; when the phoneme to be restored occurs later in the word; and when the phoneme to be restored occurs in a word, rather than in a pronounceable nonword.

Taken together, these findings indicate that contextual information plays an important role in the perception of speech. That the phenomenon is perceptual rather than merely a matter of post-perceptual guessing is indicated by the fact that restorations occur phenomenologically even when subjects are prewarned that speech sounds will be excised. Indeed, the Samuel experiments indicate that context can actually reduce subjects' ability to distinguish between a complete word with an extraneous sound superimposed on one of the phonemes and a complete word with an extraneous sound replacing one of the phonemes.

Our general modeling framework provides a natural way of accounting for these context effects in speech perception. We might imagine, for example, that speech perception takes place within a multi-level system like the one shown in Figure 19. The exact specifications of the levels of representation in speech perception and the nature of the representations corresponding to the nodes at each level are very controversial, but these are not our primary concern in the present discussion. For our purposes, it is sufficient to postulate a lexical level containing nodes for the words in English; a phonological level containing nodes for distinct phonological segments; and a pre-phonological level containing perhaps several levels of nodes for acoustic and phonetic characteristics of speech sounds, as represented in the Figure. These levels would correspond roughly to the word, letter, and feature levels postulated in the model of visual word recognition, though there would be important differences in any full model. One of these would be that the information in the input supporting many of the phonetic features would be spread over the nominal locations of several of the phonemic segments in the input (Studdert-Kennedy, 1976).

Another important difference between auditory and visual input is that all parts of a word can be presented simultaneously in the visual modality, but an acoustic input is by its very nature temporally extended, so that the information from the initial portions of a word is available for processing before information from later portions of the same word. For a word presented without any prior context, this means that the beginning of a word arrives in an unprimed system, while the later portions of the word will arrive in the system after activations at the phonological and lexical levels have had a chance to become established, and lexical activations have had a chance to begin activating phonological segments for later portions of the word.

To bring this model into contact with the phenomena reviewed above, we need to add, as we did in the case of visual word recognition, some sort of readout process. While readout may be possible from all levels, it appears that the phenomena described above can be accounted for by assuming that readout and perceptual experience are based on the activations at the phonological level. The idea would be that when the activation of a phonological segment node reached some critical activation level, the contents of that node would enter perceptual experience and could trigger overt responses such as key presses in the phoneme monitoring task or verbal utterances as in the shadowing task. These representations would also serve as the basis for subjects' judgements about whether a particular phoneme had been presented, and if so, whether it had been pronounced correctly or not.

It seems reasonably clear how a model such as ours could account for the main phenomena reviewed above. To start with the most striking phenomenon, let us consider the phonemic restoration effect. As an example we can use the sentence used by Warren, from which he removed the underlined letter:

> The state governors met with their respective legi<u>s</u>latures convening in the capitol city.

Presumably, as a result of processing the sentence up to the beginning of the word containing the excised phoneme, the node for the word 'legislature' has already received some priming. As the initial portion of this word begins to come in, then, this word will very soon begin to produce top-down activations, supporting the bottom-up activations of the initial phonemes, thus priming or predicting later phonemes. The missing segment will of course fail to produce any bottom-up input to the phonological level supporting the 's', but subsequent segments will continue to produce bottom-up support for the relevant phonemes, and these in turn will continue to provide further support for the word 'legislature'. Due to the semantic constraints as well as the predominant bottom-up support, 'legislature' will clearly dominate at the word level, and the 's' will simply be filled in by top-down inputs, eventually accumulating enough activation to reach threshold and give rise to the experience of perception.

Similar accounts may be given for fluent restorations of mispronunciations, and failures to detect mispronunciations. It is also easy to see how the model accounts for the fact that constraining context coming before a word can increase the likelihood that a restoration will occur and can reduce the time it takes to perceive a target phoneme and initiate a response to it.

Recently, Foss and Blank (1980) have shown that there are conditions in which a word context does not speed reaction time compared to a control nonword context. In their experiment, subjects monitored for target phonemes in unconstraining linguistic contexts, and the target phoneme could occur at the beginning of either a word or a nonword. For example, subjects listened for a word-initial g in the sentence:

> At the end of the year, the government/gatabont prepared a lengthy report on birth control.

Reaction time was the same, whether the target occurred at the beginning of a word (government) or a nonword (gatabont).

Our model would explain the absence of a context effect in this case by the fact that there is very little context operating to prepare the subject for the letter g when it is presented. The context sentences were designed to ensure that they would not predict very strongly what word might come next. Typically, the responses in phoneme monitoring tasks occur well before the end of the word is reached. This suggests that the subject is able to get enough information from the input data to trigger a response while the bottom up information for subsequent phonemes is just beginning to be processed. It is not surprising, then, that the word/nonword distinction does not make a difference in this case.

Subjects do sometimes restore word-initial phonemes, though they do so less frequently than they restore phonemes later in words. Restorations of word-initial phonemes may be due in part to prior linguistic context, when this is sufficiently constraining. However, there is evidence that subsequent context can also increase restorations, even if that context occurs as much as a second after the target phoneme itself (Foss & Blank, 1980). These findings indicate that when the bottom up information is missing, top down effects can fill it in, even if the relevant context is not processed until a little bit later.

Foss and Blank have recently proposed a model embodied in what they call a "Dual Code Hypothesis" which states, in essence, that phoneme monitoring and restoration responses can be based on the output of either of two levels, a pre-lexical level and a post-lexical level. The pre-lexical level provides a veridical analysis of the input, and so cannot be responsible for restoration effects. These arise only from the output of the post-lexical level. The lexical access process can be influenced by context, and lexical access can occur with an incomplete specification of the phonetic features of the input. Outputs from the post-lexical level occur after a word is actually recognized. Thus, their model seems to predict that restoration and related effects can only occur in actual words. However, Samuel (1979) has recently shown that restoration can occur in phonologically legal nonwords as well, albeit less frequently than it occurs in actual words. Our model is consistent with such restorations, since partial activations of one or more words partially consistent with the context would be producing feedback which could fill in a missing letter.

This brief treatment of a complex literature cannot do full justice to all of the interesting phenomena of speech perception, nor can we hope to provide a completely convincing account without actually carrying out a detailed simulation. There are several phenomena which we have not considered here at all, including the fact that within-word context can make it easier to detect gross mispronunciations of words (Cole, 1973; Marslen-Wilson & Welsh, 1978; such effects, it has frequently been argued, depend upon the fact that the detection that a word has been mispronounced often depends upon prior recognition of what the "base" word must be — presumably it is this prior recognition of the base word which is facilitated by context). Nevertheless, this brief treatment should be sufficient to show that the interactive activation model provides a reasonably natural framework for accounting for context effects in speech perception, just as it does for context effects in visual word recognition.

Conclusion

The model we have explored in this paper attempts to explain the role of familiar context in perception in terms of simple excitatory and inhibitory interactions among large populations of very simple neuron-like units. In these respects the model is a part of a recent trend toward trying to apply neural or neural-like models to cognitive processes (Anderson, 1977; Grossberg, 1980; Hinton, 1977; see Hinton and Anderscn, in press for a recent review of some of this work).

We have found our simulation method to be exceptionally useful for the study of complex processing systems of the kind we have described here. Time and again, during the development of this model, we found that our intuitions about how the model would behave in certain complex situations were incorrect. The use of such simulations are, in our opinion, perhaps the only way to get a sufficient handle on complex interactive process such as these to be able to make any unequivocal claims about the behavior of the system in a particular situation.

We hope that our explorations in this new domain will contribute to the growing feeling that it is a fertile one. The model we have constructed in this framework appears to provide a very close account of many of the major phenomena in word perception, including some new findings which we have presented on the way contextual inputs influence perceptual processing. The model appears also to provide a plausible framework for accounts of the perception of visually presented words in linguistic context, for the perception of phonemes in speech, and for the translation of written words and pronounceable nonwords into a phonological code.

We have focussed our analysis on the visual processing of words, though we have tried to indicate that the framework is much broader than this. We did not choose to focus on word perception because we believe that linguistic information processing involves any especially unique modes of processing. Rather, we focused on these phenomena as especially well studied examples of processes which are ubiquitous in the human information processing system;
there is a wealth of detailed experimental observations which have served to constrain and inform our model building enterprise. In addition to the extensions considered above, we are already at work constructing similar models for motor production and for concept abstraction.

Perhaps the single most unique feature of our account is that we have offered a single mechanism for the processing of both familiar stimuli, and items which are structurally similar to familiar stimuli but which are not themselves familiar wholes. Specifically, the mechanism has been used to account for the perception and pronunciation of both familiar words and novel pseudowords. Most previous models which have attempted to account for perception of novel but structurally regular stimuli have relied upon the use of a stored system of rules. We have shown how, through the use of interactive processes, the mere activation of stored representations of familiar patterns can suffice, at least to account for the perception of letters in novel pseudowords. There are many problems to be overcome before such a mechanism can be applied to all instances of processing novel, structurally regular patterns, and it is not now clear whether it may not be necessary in some cases to postulate the use of stored systems of abstracted rules. However, our explorations suggest that it may be fruitful to continue exploring the possibility that other types of apparently rule-governed behavior may be accounted for by synthesis of stored knowledge about individual cases.

One way of viewing our model is as a very general sort of retrieval mechanism in which a partial description (c.f. Norman and Bobrow, 1979) can be entered into the system (in the case of word perception in the form of a few visual features) as a kind of retrieval cue. If the features can be interpreted in terms of a unique stored item (in this case a word) the system will operate in such a way as to "fill in" the missing pieces and construct a familiar, previously stored whole. If there is no stored unique item in memory (as in the case of pseudowords), the system will instead generate a pattern of activation which represents a kind of prototype, abstracting the generally shared properties of the various similar items stored in memory. In this case, the set of similar items will act very much like the single unique item, and reinforce and "fill in" the pieces of an item which is not stored. On the other hand, if a randomly constructed description is entered (as in the case of an unrelated letter string), the patterns of higher level activations more or less cancel each other out and no "filling in" will occur.

It should be emphasized that the work presented here is intended to by synthetic and draw from a variety of other closely related developments in cognitive modeling. In addition to synthesizing our own previous efforts at building perceptual models (c.f. McClelland, 1979; Rumelhart, 1977), we have tried to combine features of the associative memory work of Anderson (1977), Kohonen (1977) and the various other parallel models of associative memory discussed in Hinton and Anderson (in press), with some of the features of Grossberg's (1980) neural modeling approach, the work on "relaxation" methods in use in computer vision work (c.f. Hinton, 1977) and Levin's (1976) Proteus activation framework for modeling cognitive processes. All of these approaches are similar to our own and we believe that further exploration of models in this general framework will turn out to be very useful.

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APPENDIX 1: Pairs of stimulus items for Experiments 1, 2, 3, 5, and 6, organized by serial position and word frequency.

Serial Position 1

Word Frequency:	hi	mhi	mlo	lo
	bill will	ball tall	aunt hunt	aide tide
	call hall	band sand	bake cake	airy wiry
	call wall	base ease	barn earn	awed owed
	came name	bath path	beef reef	bail hail
	came same	beat heat	beer deer	bail nail
	clay play	beat seat	bend lend	bale dale
	cold hold	boat coat	blew flew	bang yang
	come home	bold mold	boil foil	bell yell
	come some	bond pond	bolt colt	bite rite
	cost lost	bone tone	bomb tomb	blot slot
	dark park	buck luck	boot root	boil coil
	date late	cafe safe	bore core	bony pony
	dead read	cell sell	bull dull	boom loom
	deal real	cent sent	bush rush	boot hoot
	deep keep	coal goal	calm palm	buff huff
	door poor	code rode	cape tape	bump lump
	east past	cool tool	card ward	bunk junk
	ever over	cope pope	cash wash	bury fury
	face race	crop drop	chip whip	bush lush
	fear hear	cure pure	cone zone	bust lust
	feet meet	dear rear	cope rope	bust rust
	fine line	disk risk	corn horn	butt putt
	fine nine	drew grew	curt hurt	cart tart
	five give	dull pull	damp lamp	cage rage
	four your	fail mail	dare mare	cane sane
	game name	fair pair	dawn lawn	cart hart
	gone none	fall hall	deaf leaf	cite rite
	hand land	farm warm	dice mice	clip slip
	hell tell	fast vast	dick kick	clue glue
	here were	fear hear	dill mill	comb tomb
	just must	feed seed	dish fish	cork pork
	kind mind	fell hell	doll toll	dale yale
	late rate	file mile	dose pose	dame fame
	lead read	fill till	fail tail	dame tame
	look took	flow slow	fake rake	damp ramp
	lord word	foil soil	fate gate	dash lash
	love move	food wood	fist mist	deed heed
	make take	fort port	fond pond	deer peer
	much such	gain rain	fool wool	dell yell
	rest test	gate kate	fork pork	dock mock
	rest west	gear wear	gang rang	doll moll
	that what	harm warm	gift lift	dose hose

then when

hate kate
hero zero
hide ride
hill kill
hole role
item stem
jack lack
king ring
laid maid
laid paid
lake sake
lock rock
lose nose
main pain
male tale
mark park
mass pass
meat neat
meat seat
mike pike
mile pile
mold sold
mood wood
moon noon
nice vice
nick sick
nine wine
none tone
note vote
pace race
page wage
pale sale
pick sick
pink sink
rice vice
ride wide
ring sing
root foot
sake wake
save wave
send tend
talk walk
tire wire

glow plow
grim trim
hail sail
hang sang
hank tank
hart wart
heap leap
hide tide
hire tire
hull null
jail rail
jane lane
jean lean
jeep weep
jess mess
joke woke
jump pump
kent vent
lest nest
link zink
lung sung
maid raid
meal seal
peak weak
pile tile
plug slug
pole sole
pony tony
pray tray
rank sank
rent tent
ripe wipe
ross boss
sing wing
sore tore
tale yale
torn worn
warn yarn

drab crab
duck suck
duel fuel
dusk rusk
earl karl
fake jake
fare mare
gall rall
gary wary
gaze haze
gore lore
gore tore
grey prey
halt walt
haze maze
hazy lazy
heel keel
hint mint
hint pint
hose mose
jist mist
joel noel
junk sunk
keen teen
lent vent
leon neon
lest zest
link mink
lion zion
lone zone
lore sore
lump pump
mink wink
moll poll
mose pose
moss toss
nail sail
pact tact
pear tear
poll toll
rack sack
ross toss
seal zeal
shaw thaw
tank yank
tart wart
tile vile
tilt wilt
wing zing
wink zink

Serial Position 2

Word Frequency:	hi	mhi	mlo	lo
	came come	ball bill	acid amid	aged awed
	fall full	band bond	bare bore	bail boil
	firm form	beat boat	barn burn	bang bong
	gave give	desk disk	bass boss	bern burn
	held hold	farm firm	bell bull	blot boot
	list lost	fast fist	belt bolt	chip clip
	live love	fell fill	cane cone	cite cute
	mass miss	hang hung	cape cope	dame dome
	most must	hell hill	chin coin	deel doll
	past post	lack luck	colt cult	dick duck
	read road	lead load	core cure	dock duck
	same some	lean loan	cult curt	fare fore
	want went	lock luck	dash dish	feat fiat
	well will	mail mile	dave dive	hint hunt
		nine none	deck dick	idle isle
		pack pick	dill doll	joan juan
		pale pile	fail foil	lamb limb
		pipe pope	fled fred	lash lush
		rang ring	golf gulf	leon lion
		ride rode	gram guam	lest lust
		rise rose	hart hurt	limp lump
		role rule	jean joan	lore lure
		sand send	lamp limp	mast mist
		shop stop	neon noon	mink monk
		shot spot	owen oxen	oven oxen
		sing song	pile pole	pill poll
		slow snow	ripe rope	pony puny
		tall till	ross russ	rape ripe
		wire wore	sang sing	sack suck
			sank sink	sank sunk
			scar star	scan span
			slim swim	seam swam
			snap soap	shed sped
			tale tile	skip slip
			tire tore	slit spit
			vain vein	slug smug
			wake woke	walt wilt
			warn worn	wary wiry

Serial Position 3

Word Frequency:	hi	mhi	mlo	lo
	came case	bear beer	bake bear	babe bake
	feel fell	beat belt	belt bent	babe bale
	feet felt	bold bond	blew blow	bolt bout
	file fine	coal cool	boil bowl	bust butt
	fine fire	deck desk	bolt boot	cage cake
	game gave	diet dirt	bone bore	cage cave
	hand hard	draw drew	bulk bunk	cane cave
	head held	film firm	cafe cape	chap chip
	home hope	flew flow	cake cane	cobb comb
	knew know	foot fort	coin corn	cock cork
	life like	grew grow	cone cope	dale dame
	line live	july jury	damn dawn	dual duel
	made make	lake lane	dare dave	duck dusk
	more move	load lord	dice dive	fake fare
	part past	load loud	dick disk	fold fond
	race rate	meat meet	dome dose	hail haul
	than then	mile mine	drag drug	hose howe
	went west	mold mood	fake fame	knit knot
	wide wife	nice nine	fiat fist	lend lest
	wish with	none note	foil fool	lone lore
		page pale	folk fork	mare maze
		pick pink	fond ford	mint mist
		pike pile	gate gaze	mock monk
		poet post	gram grim	peak peck
		race rare	halt hart	pear peer
		rice ride	hank hawk	pray prey
		ride rise	hide hire	pulp pump
		safe save	hunt hurt	rail rall
		sake sale	mare mate	rake rape
		seat sent	neat nest	ripe rite
		seed send	pile pipe	robe rope
		ship shop	pole pose	sack sank
		shot shut	rage rake	slit slot
		sick sink	rice ripe	spat spit
		site size	rush ruth	spin spun
		soil soul	silk sink	suck sunk
		step stop	soap soup	swam swim
		tail tall	sole sore	tart taut
		talk task	span spun	visa vita
		team term	tale tape	walt wart
		tent text	tide tile	
		test text	tony tory	
		wage wave	tube tune	
		wake wave	wipe wise	
		wild wind		

wine wire
wire wise

Serial Position 4

Word Frequency:	hi	mhi	mlo	lo
	data date	band bank	alec alex	alan alas
	dead deal	bear beat	bare barn	bald bale
	east easy	bond bone	beef beer	bloc blot
	even ever	card carl	bell belt	bong bony
	face fact	cash cast	bend bent	boom boot
	feed feel	coal coat	bold bolt	bulb bull
	feel feet	cook cool	bulk bull	burn burr
	find fine	dean dear	calf calm	burr bury
	fire firm	ease easy	chin chip	bush bust
	half hall	fail fair	cope copy	chap chat
	held help	file film	core corn	chic chip
	kind king	food foot	cure curt	coil coin
	loss lost	fool foot	damn damp	cord cork
	pass past	ford fort	dice dick	dame damp
	plan play	gold golf	dish disk	deed deer
	read real	greg grew	drug drum	disc dish
	seem seen	hear heat	dull duly	drab drag
	shot show	herd hero	earl earn	fore fork
	than that	hole holy	fish fist	gala gall
	them then	load loan	fled flew	haze hazy
	walk wall	lose loss	ford fork	heed heel
		luck lucy	grab gram	hind hint
		maid mail	greg grey	hood hoot
		mail main	grim grin	idle idly
		mark mary	hang hank	keel keen
		meal meat	harm hart	knot knox
		mile milk	leaf leap	lamb lamp
		mood moon	lime limp	lend lent
		nice nick	mild mill	lied lieu
		pace pack	owed owen	limb limp
		pain pair	pile pill	lush lust
		pale palm	pine pint	mare marx
		plug plus	plot plow	marr marx
		poem poet	pond pony	mink mint
		pool poor	pork port	mose moss
		rice rich	raid rail	peak pear
		rise risk	rang rank	pole poll
		roof root	rosy ross	reed reef
		sale salt	rush russ	roam roar
		seed seek	rusk rust	sane sank
		self sell	sand sang	scan scar
		send sent	sing sink	slip slit
		shop shot	slim slip	slug slum

tale tall	spun spur	sole solo
talk tall	tore tory	span spat
tend tent	trap tray	spin spit
wind wine	trig trim	sung sunk
	warn wart	swam sway
	weak wear	thom thor
	yard yarn	thor thou
		tile tilt
		trig trio
		wart wary
		whig whip
		wing wink
		yang yank
		zing zink

APPENDIX 2: Stimuli used in Experiments 4, 7, and 8. The words were used in all 3 experiments, the nonwords were used in Experiment 7.

Serial Position One

Words		Nonwords		Words		Nonwords		Words		Nonwords	
bath	path	batt	patt	cure	pure	cura	pura	heap	leap	heas	leas
beef	reef	beew	reew	curt	hurt	curn	hurn	heel	keel	hees	kees
bend	tend	beng	teng	dare	fare	darp	farp	hero	zero	hera	zera
blew	flew	bles	fles	dark	park	dard	pard	hint	mint	hiny	miny
blot	slot	blom	slom	dawn	lawn	dawk	lawk	hire	tire	hird	tird
boat	coat	boap	coap	deal	meal	deag	meag	just	lust	jusk	lusk
boil	soil	boin	soin	dear	fear	deap	feap	keen	teen	keer	teer
bolt	colt	bolf	colf	deed	feed	deen	feen	keep	weep	keet	weet
bond	pond	bonn	ponn	dish	fish	disy	fisy	kick	sick	kich	sich
boom	loom	bood	lood	disk	risk	dist	rist	king	wing	kint	wint
boot	hoot	bool	hool	dock	rock	doch	roch	lack	rack	lact	ract
bore	sore	bora	sora	door	poor	doot	poot	land	hand	lant	hant
boss	moss	bosk	mosk	drab	grab	dran	grat	lest	west	lesh	wesh
buck	duck	buch	duch	duel	fuel	duen	fuen	link	pink	lind	pind
buff	huff	buft	huft	dull	null	duld	nuld	look	took	loow	toow
bump	jump	bumb	jumb	face	race	fach	rach	lung	sung	lund	sund
bunk	junk	bung	jung	fair	pair	faip	paip	mail	jail	mait	jait
butt	putt	buth	puth	farm	harm	farn	harn	mass	pass	mase	pase
calm	palm	calt	palt	feet	meet	feem	meem	moon	noon	moop	noop
cape	tape	cade	tade	fill	mill	fily	mily	much	such	muct	suct
cash	dash	cass	dass	fist	mist	fisy	misy	name	fame	namp	famp
cent	vent	cenk	venk	flow	slow	flon	slon	nose	dose	nosk	dosk
clay	play	clar	plar	food	mood	foow	moow	pact	tact	pach	tach
clip	slip	clin	slin	fort	port	fory	pory	pain	rain	pait	rait
coal	goal	coan	goan	four	your	foug	youg	peak	weak	peam	weam
cold	mold	colm	molm	gaze	haze	gazi	hazi	poll	toll	polt	tolt
comb	tomb	comp	tomp	gift	lift	giff	liff	pray	tray	prat	tran
cool	tool	coom	toom	grey	prey	gred	pred	rage	wage	raga	waga
cope	rope	copt	ropt	grim	trim	gril	tril	talk	walk	tald	wald
corn	worn	corr	worr	hall	wall	hayl	wayl	then	when	thes	whes
cost	lost	cosh	losh	hang	gang	hane	gane	tilt	wilt	tilf	wilf
crop	drop	crot	drot	hazy	lazy	hazz	lazz	yell	cell	yelk	celk

Serial Position Two

Words		Nonwords		Words		Nonwords		Words		Nonwords	
bail	boil	bain	boin	gave	give	gavy	givy	read	road	reat	roat
ball	bell	balf	belf	glad	goad	glan	goan	ride	rode	ridy	rody
band	bond	bant	bont	golf	gulf	gole	gule	ripe	rope	ript	ropt
bang	bong	bano	bono	gram	guam	grat	guat	rise	rose	rist	rost
bare	bore	bary	bory	hang	hung	hane	hune	role	rule	rolt	rult

barn	burn	barm	burm	held	hold	helf	holf	sack	suck	sace	suce
bass	boss	basy	bosy	hell	hill	hele	hile	same	some	samp	somp
beat	boat	beap	boap	hint	hunt	hiny	huny	sand	send	sany	seny
belt	bolt	bele	bole	lamb	limb	lamn	limn	sang	song	sanc	sonc
bill	bull	bilt	bult	lamp	lump	lamy	lumy	sank	sunk	sann	sunn
blot	boot	blop	boop	lash	lush	lase	luse	scan	span	scal	spal
came	come	camy	comy	lead	load	leal	loal	scar	star	scap	stap
cane	cone	cang	cong	lean	loan	leat	loat	seam	swam	sead	swad
cape	cope	capt	copt	lest	list	lese	lise	shed	sped	shes	spes
chin	coin	chid	coid	live	love	livy	lovy	shop	stop	shon	ston
chip	clip	chil	clil	lock	luck	loch	luch	shot	spot	shom	spom
cite	cute	cith	cuth	lore	lure	lorn	lurn	skip	slip	skir	slir
colt	cult	colf	culf	lost	lust	losk	lusk	slim	swim	slin	swin
core	cure	corm	curm	male	mile	malf	milf	slit	spit	slil	spil
dame	dome	damb	domb	mass	miss	mase	mise	slow	snow	slon	snon
dash	dish	dast	dist	mast	mist	masy	misy	slug	smug	slul	smul
deck	dock	dece	doce	mink	monk	minn	monn	snap	soap	snat	soat
dell	doll	deld	dold	most	must	mosy	musy	tale	tile	tald	tild
desk	disk	dese	dise	neon	noon	neot	noot	tall	till	talf	tilf
dive	dove	divy	dovy	nine	none	ning	nong	tire	tore	tird	tord
fail	foil	faid	foin	pack	pick	pach	pich	vain	vein	vaid	veid
fall	fell	fale	fele	past	post	pask	posk	walt	wilt	walf	wilf
fare	fore	farn	forn	pile	pole	pild	pold	want	went	wank	wenk
farm	firm	fard	fird	pill	poll	pilt	polt	warn	worn	warl	worl
fast	fist	fass	fiss	pipe	pope	pipt	popt	wary	wiry	wark	wirk
feat	fiat	fead	fiad	pony	puny	pone	pune	well	will	welk	wilk
fill	full	fild	fuld	rang	ring	rane	rine	wire	wore	wirr	worr

Serial Position Three

Words		Nonwords		Words		Nonwords		Words		Nonwords	
babe	bake	nabe	nake	folk	fork	rolk	rork	pulp	pump	fulp	fump
bear	beer	kear	keer	fort	foot	gort	goot	race	rate	wace	wate
belt	bent	nelt	nent	game	gate	vame	vate	rape	rare	lape	lare
blew	blow	clew	clow	gave	gaze	bave	baze	rice	rise	fice	fise
bold	bond	rold	rond	gram	grim	fram	frim	ride	ripe	fide	fipe
bone	bore	rone	rore	hail	haul	lail	laul	robe	rope	sobe	sode
boot	bout	coot	cout	hand	hard	mand	mard	sack	sank	cack	cank
bulk	bunk	lulk	lunk	hide	hire	lide	lire	safe	sake	dafe	dake
bust	butt	sust	sutt	home	hope	bome	bope	seat	sent	yeat	yent
cafe	cage	mafe	mage	hunt	hurt	junt	jurt	ship	shop	thip	thop
cake	came	yake	yame	july	jury	ruly	rury	shot	shut	thot	thut
cane	cape	fane	fape	lake	lane	hake	hane	silk	sink	vilk	vink
case	cave	mase	mave	life	like	rife	rike	site	size	fite	fize
chap	chip	phap	phip	lone	lore	jone	jore	slit	slot	glit	glot
coal	cool	roal	rool	made	make	gade	gake	soap	soup	boap	boup
cone	cope	fone	fope	meat	meet	reat	reet	sole	sore	vole	vore
cult	curt	dult	durt	mile	mine	kile	kine	suck	sunk	cuck	cunk
dame	dare	jame	jare	mint	mist	rint	rist	swam	swim	twam	twim
damn	dawn	camn	cawn	mock	monk	fock	fonk	tale	tape	jale	jape

deck desk	seck sesk	more move	nore nove	talk task	halk hask
dice dive	wice wive	neat nest	deat dest	tart taut	lart laut
dome dose	fome fose	nice nine	bice bine	tent test	fent fest
draw drew	traw trew	none note	sone sote	than then	phan phen
drug drag	grug grag	page pale	lage lale	tide tile	dide dile
dual duel	bual buel	part past	rart rast	tube tune	bube bune
duck dusk	juck jusk	pear peer	cear ceer	visa vita	wisa wita
fake fame	pake pame	pick pink	bick bink	wage wake	vage vake
file fine	hile hine	pike pile	zike zile	went west	ment mest
film firm	wilm wirm	poet post	roet rost	wide wife	mide mife
foil fool	hoil hool	pole pose	gole gose	wild wind	lild lind
fold fond	lold lond	pray prey	cray crey	wish with	lish lith

Serial Position Four

Words	Nonwords	Words	Nonwords	Words	Nonwords
band bank	pand pank	fork fort	bork bort	pool poor	rool roor
bear beat	cear ceat	gold golf	pold polf	pork port	rork rort
beef beer	heef heer	grab gram	frab fram	raid rail	caid cail
bell belt	lell lelt	grew grey	trew trey	rang rank	jang jank
bend bent	zend zent	grim grin	drim drin	read real	nead yeal
bloc blot	gloc glot	half hall	salf sall	reed reef	yeed neef
bold bolt	rold rolt	hear heat	kear keat	roam roar	coam coar
boom boot	goom goot	heed heel	meed meel	roof root	doof doot
bulb bull	julb jull	held help	deld delp	rush rust	cush cust
burn bury	durn dury	hind hint	nind nint	sand sank	nand nank
bush bust	sush sust	hood hoot	pood poot	seed seen	leed leen
calf calm	malf malm	keel keen	deel deen	self sell	relf rell
cash cast	tash tast	kind king	lind ling	send sent	nend nent
chap chat	shap shat	lamb lamp	mamb mamp	shop show	thop thow
chin chip	phin phip	leaf leap	seaf seap	sing sink	ting tink
coal coat	hoal hoat	lend lent	jend jent	slim slip	plim plip
coil coin	hoil hoin	limb limp	mimb mimp	slug slum	flug flum
cook cool	sook sool	load loan	coad coan	sole solo	fole folo
cord corn	rord rorn	loss lost	foss fost	sung sunk	cung cunk
damn damp	bamn bamp	lush lust	fush fust	swam sway	twam tway
data date	yata yate	mail main	yail yain	talk tall	lalk lall
deal dean	ceal cean	meal meat	weal weat	tend tent	yend yent
deed deer	teed teer	mild milk	lild lilk	than that	phan phat
disc dish	lisc lish	mink mint	bink bint	them then	shem shen
drab drag	trab trag	mood moon	rood roon	trap tray	arap aray
drug drum	grug grum	pain pair	wain wair	trig trim	crig crim
dull duly	rull ruly	pass past	wass wast	walk wall	ralk rall
fail fair	dail dair	peak pear	meak mear	warn wart	larn lart
feed feel	beed beel	plan play	blan blay	weak wear	veak vear
fish fist	rish rist	plug plus	blug blus	wind wink	vind vink
fled flew	pled plew	poem poet	boem boet	yang yank	mang mank
food foot	nood noot	pond pony	rond rony	yard yarn	mard marn

APPENDIX 3: Stimuli used in Experiment 9 (good and poor nonwords).

Serial Position One

Good		Poor		Good		Poor		Good		Poor	
arma	orma	arun	orun	dore	hore	dyld	hyld	midy	lidy	mesc	lesc
bamp	mamp	byar	myar	fick	gick	furg	gurg	mish	lish	mouf	louf
bant	mant	baes	maes	flad	slad	fogn	sogn	mita	lita	meof	leof
bawn	mawn	buef	muef	flar	slar	fibo	sibo	miva	liva	mahe	lahe
baze	caze	boib	coib	flen	slen	fiaf	siaf	mong	fong	muaf	fuaf
beel	deel	bydy	dydy	flod	slod	fimn	simn	nome	pome	nuah	puah
bena	mena	byal	myal	flum	clum	femn	cemn	pait	mait	poec	moec
beng	heng	biez	hiez	foon	poon	fuax	puax	pake	dake	prup	drup
blay	glay	bipo	gipo	gint	kint	gaxt	kaxt	payo	tayo	piul	tiul
bood	lood	becu	lecu	grot	crot	gunc	cunc	pock	gock	preb	greb
bour	lour	boeu	loeu	hame	wame	hevu	wevu	pyra	tyra	piob	tiob
brip	prip	byst	pyst	hine	bine	hupo	bupo	rean	pean	ryrl	pyrl
bung	pung	bigy	pigy	hode	dode	haui	daui	rere	pere	rosc	posc
cack	dack	cuie	duie	jura	rura	jonc	ronc	rire	vire	raow	vaow
cale	rale	caue	raue	lail	dail	loco	doco	rone	sone	riek	siek
cark	wark	cyrr	wyrr	lall	sall	lubt	subt	rull	sull	raih	saih
cate	wate	cyrd	wyrd	lare	sare	lufi	sufi	rure	dure	roka	doka
chan	whan	caom	waom	laye	paye	lufu	pufu	sain	dain	seob	deob
coan	boan	cuhi	buhi	leat	weat	lirg	wirg	sary	dary	sehi	dehi
coar	loar	cuey	luey	lile	dile	lufa	dufa	sead	pead	soey	poey
coll	holl	cuop	huop	lina	fina	luix	fuix	shid	thid	saue	taue
comp	bomp	cafu	bafu	ling	ging	lufy	gufy	shil	thil	surx	turx
cona	tona	cuap	tuap	lole	nole	luag	nuag	slan	blan	suik	buik
cose	tose	cauk	tauk	lont	hont	laek	haek	thap	shap	tucu	sucu
cosh	bosh	cafy	bafy	lote	hote	ledd	hedd	thed	ched	tyrb	cyrb
cown	bown	cafi	bafi	lune	rune	lizy	rizy	thew	shew	tusu	susu
cran	pran	cuol	puol	malo	balo	mewd	bewd	thim	chim	tuod	cuod
crin	brin	cafa	bafa	maly	baly	mixt	bixt	thoy	shoy	tumn	sumn
deet	reet	diez	riez	mank	pank	mozz	pozz	tolo	lolo	tiug	liug
dera	rera	dypt	rypt	mape	bape	miud	biud	toly	loly	taxx	laxx
dise	mise	doic	moic	mava	bava	myno	byno	wice	fice	wefu	fefu
dite	wite	caof	waof	mear	vear	miut	viut	wike	rike	waos	raos

Serial Position Two

Good		Poor		Good		Poor		Good		Poor	
arma	amma	oree	omee	duse	dise	hupi	hipi	mave	mive	raos	rios
atto	anto	etaw	enaw	flan	fean	klex	keex	mone	mene	noik	neik
aven	alen	ivaf	ilaf	fock	fack	koyt	kayt	pait	prit	eacu	ercu
bain	brin	eapi	erpi	gane	gine	eamy	eimy	pame	pome	zalu	zolu
bame	bome	zapy	zopy	gick	gock	zird	zord	para	pyra	laes	lyes
bamp	bomp	maec	moec	gint	gant	riow	raow	pean	pran	keug	krug
bana	bena	kati	keti	hake	hoke	jaho	joho	pide	pade	jiti	jati

bash	bosh	maec	moec	hane	hine	jatu	jitu	pite	pote	virp	vorp
bave	bove	vaep	voep	hant	hont	gawd	gowd	pung	peng	tumn	temn
bine	bene	zife	zefe	hean	hoan	yeip	yoip	rale	rile	naok	niok
boan	blan	poik	plik	heng	hing	wegy	wigy	rara	rera	katu	ketu
bont	bint	ooro	oiro	hode	hade	yozi	yazi	rike	ruke	hipo	hupo
bown	bawn	zomy	zamy	hona	hana	kowe	kawe	rina	rana	wiof	waof
bung	beng	hufi	hefi	hore	hure	oomu	oumu	rine	rane	zirr	zarr
cack	cuck	japp	jupp	hote	hite	jocu	jicu	rore	rure	yocu	yucu
cang	cung	hafy	hufy	lade	lude	hafu	hufu	rull	rell	gupp	gepp
cara	cura	yalu	yulu	lall	lell	kawk	kewk	shap	stap	uhil	util
chan	cran	ahux	arux	lant	lont	zagh	zogh	shar	slar	uhem	ulem
chim	crim	ahun	arun	lara	lyra	daol	dyol	shee	slee	uhay	ulay
cona	cana	joic	jaic	lare	lire	ealu	eilu	shil	skil	ahik	akik
coot	crot	woie	wrie	lary	lury	rafi	rufi	shum	stum	ohic	otic
cose	cuse	gosc	gusc	leal	loal	teic	toic	slad	stad	ulel	utel
crat	clat	irey	iley	lina	lona	jiku	joku	soll	sull	jogg	jugg
dain	drin	cauk	cruk	ling	leng	simn	semn	spip	swip	opak	owak
dake	doke	paes	poes	lite	lote	kixa	koxa	sten	slen	utas	ulas
dant	dunt	caop	cuop	lole	lale	yovu	yavu	tora	thra	coeb	cheb
dara	dera	yagy	yegy	lolo	lilo	koxi	kixi	tove	tave	poec	paec
dary	dery	vawk	vewk	lune	lyne	kuny	kyny	vina	vena	tibo	tebo
deen	dien	keor	kior	maly	mily	jaon	jion	wang	weng	jaod	jeod
dide	dode	gisu	gosu	mang	mong	jaik	joik	wate	wite	faos	fios
dite	dete	jipa	jepa	mase	mise	cafi	cifi	whin	wain	phef	paef
dore	dure	focu	fucu	mava	miva	kasc	kisc	wina	wana	dign	dagn

Serial Position Three

Good		Poor		Good		Poor		Good		Poor	
arge	arde	ilgi	ildi	grat	grot	phas	phos	rame	rade	temy	tedy
bain	bawn	feie	fewe	grop	grap	hyod	hyad	rara	rana	zorn	zonn
bana	bava	oino	oivo	hain	hawn	keie	kewe	rean	reen	pyar	pyer
bary	baly	voru	volu	hame	hade	yemy	yedy	rine	rive	yanu	yavu
bave	bame	yevo	yemo	hara	hana	lyrc	lync	rore	rone	wyra	wyna
beal	beel	soay	soey	hean	heen	omag	omeg	rune	rute	gyna	gyta
bere	bene	cyra	cyna	hine	hile	myno	mylo	sare	sade	oiri	oidi
bole	bote	eilu	eitu	hode	hoke	zado	zako	sary	saly	zork	zolk
boop	bomp	jaon	jamn	hoon	hoan	guow	guaw	sava	sasa	jovu	josu
brit	brot	ulim	ulom	lale	lare	zila	zira	shar	shur	twax	twux
cack	cark	oici	oiri	lell	leal	nulb	nuab	shey	shoy	vaep	vaop
cara	cana	teru	tenu	lide	lile	kudi	kuli	sile	sive	zalu	zavu
cate	cale	zetu	zelu	lina	lita	nunz	nutz	sina	sita	auny	auty
coar	cour	emat	emut	loar	lour	itam	itum	slad	slod	unai	unoi
coba	coga	geby	gegy	lote	loke	guti	guki	slan	slen	kyar	kyer
coot	cont	udoe	udne	luse	lune	kesc	kenc	slue	slee	irug	ireg
cory	coxy	lirx	lixx	malo	maro	cilm	cirm	sted	stad	aker	akar
cran	crin	axag	axig	mant	mait	numx	nuix	tare	tane	cyrn	cynn
crit	crat	lyig	lyag	mava	masa	govu	gosu	thed	thid	keex	keix
dara	dava	ciru	civu	mave	mase	tevo	teso	thew	thow	myed	myod
deat	deet	tyar	tyer	mear	meer	fuaf	fuef	thip	thap	ahik	ahak

dete	dene	outy	ouny	mide	mive	uldy	ulvy	thit	thot	puim	puom
dile	dise	zalk	zask	midy	mily	lydi	lyli	tite	tive	yotu	yovu
dore	dode	zird	zidd	mita	miva	fotu	fovu	tona	tora	vanx	varx
dran	drin	myar	myir	mone	mote	kunz	kutz	tove	tose	eavu	easu
dure	duse	kirc	kisc	nore	nole	ziry	zily	vire	vide	ooro	oodo
fane	fale	hyno	hylo	pade	pake	oldi	olki	wank	wark	emnu	emru
fite	fice	gutu	gucu	pean	peen	emay	emey	wara	wana	omru	omnu
flad	flod	hyar	hyor	pide	pite	zedi	zeti	wate	wale	fetu	felu
flar	flur	smal	smul	pone	pote	jinu	jitu	whan	whin	knae	knie
gake	gane	lyku	lynu	pran	prin	fuag	fuig	wina	wita	tunu	tutu
gara	gana	gyrn	gynn	prit	prat	fuix	fuax	wite	wike	gotu	goku

Serial Position Four

Good		Poor		Good		Poor		Good		Poor	
acho	achu	giso	gisu	ging	gint	igeg	iget	pean	pead	ulun	ulud
allo	alle	wrio	wrie	grap	grag	teup	teug	pran	prat	emun	emut
arma	armo	utca	utco	gred	gren	gyrd	gyrn	prin	prip	myen	myep
bara	bary	itea	itey	grot	grop	utet	utep	rane	rana	etie	etia
bave	bava	yefe	yefa	hame	hamp	ugoe	ugop	rary	rark	jiey	jiek
beed	beel	tuod	tuol	hara	hary	feca	fecy	rean	reat	jion	jiot
bena	bene	ilia	ilie	heer	heen	byar	byan	reer	reen	pyar	pyan
blay	blan	cyry	cyrn	heng	hent	otug	otut	rere	rera	epie	epia
bood	boop	ayid	ayip	hine	hing	awee	aweg	rore	rora	ilue	ilua
brin	brip	hyen	hyep	hona	hont	nuca	nuct	rure	rura	ipie	ipia
coar	coan	ewor	ewon	lall	lale	ikil	ikie	sall	saly	zowl	zowy
cogo	coga	nigo	niga	layo	laye	kugo	kuge	sare	sary	kewe	kewy
cona	cont	gyta	gytt	leal	leat	myal	myat	shar	shap	kior	kiop
cran	cray	zirn	ziry	leed	leen	jiad	jian	shey	sher	akay	akar
crin	crit	tyon	tyot	lide	lidy	koze	kozy	shil	shis	gnel	gnes
dail	dain	ryul	ryun	lile	lilo	loye	loyo	shum	shug	ulam	ulag
dara	dary	keca	kecy	loar	loal	fiur	fiul	sint	sina	gewt	gewa
deet	deel	ivot	ivol	lole	lolo	gece	geco	slan	slar	twon	twor
deng	dene	aheg	ahee	lona	lont	jipa	jipt	stap	stad	akep	aked
dera	dery	hufa	hufy	lood	loor	yuid	yuir	sten	sted	zorn	zord
dien	dier	cian	ciar	maly	malo	vozy	vozo	tane	tant	voye	voyt
dite	dita	gefe	gefa	mant	mank	yeot	yeok	thap	thag	keup	keug
dona	dong	upea	upeg	maro	mari	wopo	wopi	thew	thed	eiow	eiod
doon	doot	jaen	jaet	mave	mava	udne	udna	thit	thim	utut	utum
duse	dush	fege	fegh	meer	meed	cour	coud	thoy	thow	aday	adaw
fick	fice	yawk	yawe	mena	mene	upia	upie	tite	tita	ivie	ivia
fint	fina	cytt	cyta	mide	midy	ulbe	ulby	toly	tolo	ziny	zino
flar	flad	onur	onud	mita	mito	neda	nedo	vear	vean	wyrr	wyrn
flot	flod	hyat	hyad	mone	mong	udoe	udog	wang	wank	ahig	ahik
flum	flug	itam	itag	nole	noly	yede	yedy	weer	ween	kyar	kyan
gane	gana	ooce	ooca	pame	pamp	ogoe	ogop	whan	whay	lymn	lymy
gare	gara	adie	adia	payo	paye	jigo	jige	wint	wina	cebt	ceba

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